Quantum Response of Human Skin to Hydrogen Peroxide Stimulation

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Appendix 1: Brief introduction to squeezed states and their relevance for understanding biophoton signals

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Appendix 2: Comments and Responses

Appendix 3: Do biophotons originate from the decay of squeezed dark photons?

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Abstract

Visible range photon signals emitted after applying five concentrations of hydrogen peroxide (H_2O_2) on both sides of the left hand were measured and called response signals. Their quantum nature was ascertained in two analyses. The first analysis determined decay parameters of signals in two models - quantum and two exponential decays - and checked the robustness of decay parameters. The analysis established hyperbolic decay of response signals and showed that signals were in evolving squeezed states. The second analysis split response signal in small sections and determined the properties of the signal in each section from mean, variance and photon count distribution in the section. The properties showed that every section was a high strength biophoton signal having a core quantum component in squeezed state and a peripheral classical component. The properties further suggested the involvement of same or similar quantum entities in the emission of response and biophoton signals.

Keywords: Biophotons, Squeezed state, Response signal, Robust Parameters, Quantum entity.

1. Background:

Most living systems spontaneously emit visible range photons at all times. The emitted photons are called biophotons or ultra-weak photons and their signal, biophoton signal [1]. Biophoton signal of a living system is affected by various metabolic activities of the system but their effects cannot be separated and quantified in the semi classical framework normally used for describing biological phenomena. The description of biophoton signals and extraction of their properties require a new framework. Quantum framework can be used but usually it is not because the description of a phenomenon not involving pure or nearly pure quantum state is cumbersome in it. Likewise, the description of a phenomenon involving pure quantum states is much simpler in the quantum framework but very troublesome in the semi-classical framework. The possibility of using quantum framework for describing biophoton signals therefore hinges on establishing their quantum nature. The issue of establishing the quantum nature of the biophoton signal encounters three main challenges: ultra-weak strength comparable to background noise, alteration of signal because of ongoing changes in the living system emitting the signal and complications arising from system substrate interactions. The quantum nature will be easier to establish in the biophoton signal emitted by quasi-stable system without a substrate. Human hand is one such system. Its biophoton signal is easily measurable, it has been extensively studied in medical sciences and the human subject can easily report unexpected changes occurring during measurement. The biophoton signals from different body parts of human subject have been measured for a long time. The duration of measurement of a signal lies between two to five minutes [2]. The measurements provided important clues about the quantum nature of human biophoton signals [3].

Biophoton signals are measured by counting photons in contiguous same size bins using a broadband photo multiplier tube detector. The results of counting constitute time series of digitized signal for that bin size. The signal properties are determined by the analysis of time series. The analysis depends on framework and so are the properties of signal. The semi classical framework associates photon signal with probabilistic transitions of a large number of biomolecules from higher to lower energy state. The transitions of each type of biomolecule give rise to a photon mode of definite wavelength and the emitted signal decays exponentially with a definite decay rate. The signal emanating in transitions of more than one kind of biomolecules is the incoherent sum of signals from different modes. The analysis of the signal in this framework determines wavelength, decay rate and initial strength of different modes. The spectral distribution of a signal provides information of its modes. The spectral distribution of a biophoton signal is difficult to determine because of weak signal strength and use of a broad band detector.

The two features of spectral distribution of biophoton signals have been determined; they are photons mainly in visible range and broad band spectrum. Both features are problematic for the semi-classical framework. They require energy levels of biomolecules implicated in biophoton emission to have bands with substantial gap between bands and some mechanism for jumping the gap. Two other problematic but characteristic features of biophoton signals are unchanging average signal strength and fluctuations in the number of photon detected in a bin [4]. Unchanging average signal strength implies time coordination in acts of photon emission and absence of exponential decay in all contributing photon modes. It allows the study of fluctuations in photon number through statistical moments and photon count distribution in the time series of signal. The study shows that statistical moments and photon count distribution of biophoton signals contain information pertaining to probabilistic time coordination in acts of photon emission. The information is extracted as properties of a signal [5]. The adjective holistic is added to these properties so as to indicate that they are properties of signal in a macroscopic interval. The information contained in statistical moments - mean and variance - determine the holistic properties, signal strength and intercept and slope of Fano Factor curve at zero bin size. The intercept and slope of Fano Factor curve of a signal provide definitive indications of its classical or quantum nature. The properties of a signal depicting information contained in photon count distribution can be determined only if the signal is quantum and its state is guessed correctly. Fortunately, most human biophoton signals are quantum signal in squeezed state specified by four parameters $|\alpha|$, r, θ and ϕ, which permits the determination of six holistic properties from photon count distribution. The properties are four squeezed state parameters, squeezed state index (SSI) and sum of the squares of residuals (SSR). The three squeezed state parameters (r, θ and ϕ) have same values while the other properties have different values in many biophoton signals. These properties could not be determined in biophoton signals emitted mainly by stressed or sick subjects; these subjects did not emit biophoton signals in squeezed state. We, therefore, suspect that the biophoton signals emitted by homogenate of human tissue or parts separated from the subject may not be in squeezed state.

The energy source of biophoton signals has been a difficult problem for the semi-classical framework. The incessant and ubiquitous emission of visible range photons requires a universal source of energy that is accessible all the time. The biochemical currency of energy is usual source of biophoton signals but it can generate only infrared photons on its own. The generation of visible range photons needs a universal and all time operative mechanism to up-convert biochemical energy of individual reactions. The mechanism for up-conversion is different in the semi-classical and quantum frameworks. The prototype suggested mechanism is explicit in the semi-classical framework and implicit in the quantum framework. The explicit mechanism envisages a chain or chains of chemical reactions involving reactive oxygen species for

generating visible range photons [6-7]. The implicit mechanism envisages channeling of the energy of biochemical reactions involving constituents of a quantum entity into a single photon mode for generating visible range photons. The explicit mechanism would produce a classical photon signal, whose properties would be specific to biomolecules involved in the chains of chemical reactions and whose shape would have exponential decay character because of the probabilistic kinetics of chemical reactions. In contrast, the implicit mechanism would produce a quantum photon signal, whose properties would be specific to the state of quantum entity and whose shape would depend on dynamic evolution of the quantum state. The operative mechanism can be determined by ascertaining the nature of biophoton signals; classical nature would imply explicit mechanism and quantum nature would imply implicit mechanism of up-conversion.

The nature of a photon signal is ascertained by detecting time coordination in its photon emission. The easily detectable types of time coordination are normal and probabilistic. Any definite shape of signal reveals normal time coordination while any definite photon count distribution in the signal reveals probabilistic time coordination. However, exponentially decaying shape is usually attributed to probabilistic decay of a large number of identical biomolecules and is not considered to depict normal time coordination. Normal time coordination may occur in a classical signal if a mechanism exists for transmitting necessary instructions/information to implicated biomolecules for coordinating their photon emitting acts. No such mechanism has been found in any living system so far and hence, normal time coordination of biophoton signals has to be attributed to their quantum nature. The unchanging average signal strength of biophoton signals exhibits normal time coordination and it has to be considered as indicative evidence of quantum nature of signals. Definitive evidence of their quantum nature is provided by photon count distribution, which is not normal but akin to Poisson distribution in most biophoton signals. Photon count distribution succeeds in determining quantum state in many human biophoton signals [9-11]. Some far reaching implications emanate from the determination of quantum state of biophoton signal emitted by a living system. It implies the existence of quantum entity in specific state in a living system. The quantum entity should be a macroscopic composite object and all biomolecules implicated in the emission of biophoton signal should be the constituents of the composite object. The features of the living system emanating from the quantum entity should be holistic and should depend on the state of quantum entity. Biophoton signal and some other holistic properties of a living system should change with the change in the state of its quantum entity. How to change the state of quantum entity? We fortuitously discovered a simple procedure for changing the state of quantum entity that emits spontaneous biophoton signal from a portion of human skin. The quantum entity switches to different states on applying different concentrations of hydrogen peroxide (H_2O_2) on the portion of skin. The changed states slowly

evolves to the original state. We detected the changed states and their evolution by measuring visible range photon signals emitted after the application of H_2O_2 and showing them to be quantum signals.

Rastogi and Pospíšil observed enhanced emission of visible range photon from human skin after the application of H_2O_2 and the persistence of enhanced emission for hours [12]. They observed similar enhancement of visible range photon emission in plants as well [13, 14]. The enhanced emission in many living system was intriguing, which suggested a role of H_2O_2 in biophoton emission and/or energy up conversion. The nature of the role was investigated by analyzing visible range photon signals emitted by portions of skin at two anatomical sites of a human subject after applying five concentrations of H_2O_2 to them. These signals were called response signals in order to differentiate them from biophoton signals. The response signals had a characteristic shape. Every signal had a slowly decaying initial region followed by a long tail. The signal strength decayed continuously with decreasing rate. The decay was observed with bin size of 50ms for a duration varying from 9 min to 63 min in different signals. The number of photons detected in a bin fluctuated in the entire duration. Two analyses were performed in each response signal. The first analysis determined decay parameters in different versions of signal in semi-classical and quantum. The different versions of a signal corresponded to measuring of the signal using different bin size. The analysis checked the robustness of parameters of a signal to change in bin size. The robustness determined the validity of the two models. The description of every response signal was invalid in the semi-classical model but valid in the quantum model. The quantum model envisaged response signal to be a quantum signal in an evolving squeezed state [15]. The second analysis split every response signal into 3 min contiguous sections, ignored the decay of signal in a section and estimated squeezed state parameters of signal in each section. The estimations yielded same values of three squeezed state parameters in all but a few initial sections of response signals. These values were identical to the values obtained in biophoton signals. The second analysis established quantum nature of response signals and suggested same or similar origin of response and biophoton signals.

The quantum model was proposed earlier for describing delayed luminescence signals that are emitted by living systems after a few seconds exposure to light [16]. They are visible range photon signals and their shapes are similar to the shapes of response signals. The quantum model obtains shape of a single mode evolving quantum photon field in squeezed state in adiabatic approximation. The evolution is governed by phenomenological Hamiltonian of a frequency stable anharmonic oscillator with time dependent damping and mass terms [17]. The calculated expression contains four parameters and has non-decaying and decaying components. The quantum model identified non-decaying component as spontaneous biophoton signal and decaying component as delayed luminescence signal. The identification obliterated the

distinction between delayed luminescence and biophoton signals. The model justified calling delayed luminescence signals as biophoton signals. The shape of delayed luminescence signals provided only supportive evidence for the quantum model but did not truly validate it. The true validity required ascertaining the quantum squeezed state of both biophoton and delayed luminescence signals, which has been done in biophoton signals but not in delayed luminescence signals though quantum nature of a few delayed luminescence signals has been ascertained [18]. The two analyses of response signals removed the lacuna in the validity of quantum model. The first analysis validates the expression of shape in the model and the second analysis ascertains quantum squeezed nature of every 3min section of response signals and same or similar nature and origin of response and biophoton signals.

The plan of the paper is as follows: section 1 provides background and reasons for studying human response signals and main results of the study; section 2 briefly describes measuring system, protocol of measurements, procedure used for analyzing time series of decaying and non-decaying signals and properties of signals determined in the analyses; section 3 presents the results of analyses as properties of response and biophoton signals and discusses their implications particularly, for the presence of quantum entity in a living system and quantum nature of life; and section 4 enumerates the findings of our study.

2. Material and Method:

2.1: Measuring system: The measuring set up was fabricated by Cohen and Popp for studying human biophoton emission from different anatomical sites [1, 19]. The set up was housed in two adjacent rooms, a dark room and a control room. The dark room was light tight and (2.5m x 1.2m x 2.7m) in dimension. The entry to the dark room was through a door from the control room. The dark room contained an examining bed, a pillow filled with sand, a wooden block, a stool and photon-counting device mounted on a movable platform that could be steered remotely from the control room. The subject sat on the stool in the dark room before and during measurement. The subject put his hand at the specified position on the bed in the dark by the help of wooden block and pillow. The control room contained electrical equipment (high voltage power supply, controllers of shutter and steering system, air moisture filter, cooling unit and computer for data acquisition). The steering system could manipulate the position of photon-counting device in three directions with an accuracy of 1mm. The photon-counting device was EMI 9235 QB (selected type) photomultiplier tube operating in single photon counting mode. The spectral sensitivity of the photomultiplier was in the range of 160nm-630 nm with two peaks of nearly 30% sensitivity at 200nm and 350nm. The detector was enclosed in thick metal encasing that had a sealed quartz window on one side. A computer operated mechanical shutter controlled the opening and closing of the window. A ring of 9cm diameter protected the quartz window and its shutter from

mechanical shocks. The temperature of the photomultiplier was maintained at -25°C for optimal efficiency with least electronic noise. The details of the design, fabrication and measuring procedure were mentioned in papers by members of Popp group in many conferences and summer schools. The selection of PMT tube was a crucial step in getting low noise and high sensitivity. The manufacturer indicates exceptionally low noise in a PMT tube by mentioning selected type in parentheses. The PMT tube was cooled to -25^0C and background noise of the system got stabilized only after a few hours of cooling. This was the optimal temperature determined from the trade-off between sensitivity and low noise. The discriminating levels used for registering counts were adjusted by calibrating observed and expected counts emitted by a standard radioactive source. The dark room was small and had a minimum of furnishing. Its light was not switched on for many hours before measurements. The software used for capturing counts was written by a research student few years earlier but was not crucial. The systems fabricated later use LabVIEW and give similar results. The back ground noise was checked regularly and its higher value indicated the need of cleaning of dark room and system.

2.2: Subject and measuring protocol: The subject was a healthy male person of 26 year age, who voluntarily agreed to apply 500µl of H_2O_2 on nearly $30cm^2$ portion of his skin first on the dorsal and then on the palm sides of his left hand on any day. Five concentrations (100mM, 200mM, 300mM, 400mM and 500mM) of H_2O_2 were applied on different days in a span of 15 days. The subject wore a black glove on his left hand for at least half an hour before entering the dark room. He removed the glove after entering the dark room and sat quietly for 15min by the side of measuring table on a stool. The wearing of glove and waiting period eliminated any photon emission arising from earlier exposure of hand to ambient light. Signals from the left hand were measured in sections of 3min by counting photons in 3600 contiguous bins of 50ms. There was a gap of nearly 1.6 s between measurements of two successive of sections due to closing and opening of the shutter. Only one section was measured in non-decaying signals but many sections in decaying signals. The following was the order of measurements on any day: background noise with shutter close, background noise with shutter open, spontaneous signal from a portion on the dorsal side, spontaneous signal from a portion on the palm side, response signal from the portion on the dorsal side, response signal from the portion on the palm side and background noise with shutter open. Three sections of spontaneous biophoton signals from the two portions were measured on the first day. The gap between the sections was 5min. After measuring spontaneous biophoton signals, the subject applied H_2O_2 on the portion of skin at the dorsal side of his left hand in the dark and immediately put the applied portion below the photomultiplier for measuring response signal from the dorsal side. The time between applying of H_2O_2 and measuring of first section was less than 3s. The measuring of sections was continued till the subject got tired or stopped feeling the irritation. The subject relaxed in the dark room for

5min and then applied H_2O_2 on the portion of skin on the palm side of left hand for measuring response signal from the palm side. The number of sections varied from 3 to 21 in different response signals differed.

2.3: Procedure for calculating properties of a non-decaying section: The outcomes of counting photons in 3600 contiguous bins of size 50ms constituted the time series for 50ms. This time series was fine grain version of the digitalized signal in a section. The coarse grain versions of this signal were time series for measuring with higher bin sizes. The time series for bin size equal to integral multiple of 50ms were obtained by merging counts in appropriate number of bins of the time series for 50ms. They contained fewer outcomes e.g. the time series of the coarse grain version for 150ms was obtained by merging counts of three bins of the time series for 50ms and contained 1200 outcomes. We used hundred time series corresponding to bin size from 50ms to 5s for obtaining properties of a section of non-decaying signal. Mean and variance of hundred time series were corrected for background noise by subtracting the mean and variance of time series for same bin size of the background noise signal measured with closed. The corrected mean determined signal strength. The signal strength was same in all versions of a signal i.e. it was independent of bin size. It was, therefore, a property of the signal. It was expressed in counts/50ms.

The corrected (and uncorrected) variance was different in time series of different versions of a signal and varied wildly with bin size of time series. A procedure was required for obtaining the property of signal connected with variance. Variance was first normalized by dividing with mean of the time series. The normalized variance is called Fano Factor. Fano Factor varied rapidly on bin size of time series and appeared to fluctuate around a curve, called Fano factor curve. An analytical form of the curve was determined by fitting Fano Factor in 100 versions with second degree polynomial in bin size. The intercept and slope of the curve, determined two properties of signal of the section.

Photon count distribution of the time series determined other properties of non-decaying section of a signal. Photon count distribution is the set of probabilities of detecting various number of photons in a bin. The probabilities were determined by the frequencies of counting different numbers of photons in a bin in the time series. The time series of different versions of a signal yielded different sets of probabilities. The probabilities of detecting photons up to the maximum number of photons detected were used for estimating three squeezed state parameters r, θ and ϕ [20]. The estimation compared the observed probabilities to the probabilities obtained by convoluting probabilities in the background noise signal with analytical expressions of the probabilities of detecting photons in a squeezed state signal with corrected signal strength [21]. The program **fminsearch** of MATLAB7.0.4.365 (R14) with TolX=1e-08 and TolFun=1e-06 was

used for estimation. The estimated value of r and signal strength determined the fourth squeezed state parameter $|\alpha|$. The sum of the squares of residuals of probabilities in the time series of 50ms at the best fit was named SSR. The average value of SSR over number of observed probabilities appeared to be a property of the section and it provided an estimate of classical component present in the signal.

The validity of quantum description was ascertained by estimating squeezed state parameters in many versions and combination of versions of a signal. Nineteen estimations of parameters were made in each section; ten estimations were with ten versions for bin sizes from 50ms to 500ms and nine estimations were with combinations of the ten versions [22]. Most estimations yielded r = 2.72 10^{-10}, θ = 101.91^o and ϕ=69.53^o in overwhelming majority of signals. These values with error of 0.1% were, therefore, identified as universal values of three parameters. The signal of a section was considered to be in a squeezed state if all nineteen estimations yielded universal values of three squeezed state parameters, in a state close to the squeezed state with some admixture of other states if some but not all estimations yielded universal values and in an undetermined state if no estimation yielded universal values. Squeezed state index (SSI) was introduced for indicating closeness of the state of a signal to the squeezed state with universal values of three parameters. SSI was a weighted sum of nineteen estimations yielding universal values [22]. SSI turned out to be a property of signal in the section. Photon count distribution thus determined six properties-r, θ, ϕ, $|\alpha|$, SSR and SSI. All these properties belonged to the entire time series of section and were holistic in nature.

2.4: Procedure for calculating decay parameters of a response signal: A response signal was obtained by joining all measured 3min sections from a portion for one concentration. It was the fine grain version of response signal. It had an initial missing region of nearly 3s and missing regions of 1.6s between two adjacent sections. Coarse grain versions of the response signal for bin sizes up to 3min were obtained from the fine grain version. The decay parameters in three thousand and six hundred versions were estimated in the two models. The first model was in the semi-classical framework and the second model was in the quantum framework. The photon signal in the first model was ascribed to probabilistic transitions of a large number of biomolecules of one type from higher to lower energy state. Photon signal, in the model, decays exponentially with decay rate depending mainly on transiting biomolecules. The signal arising from transitions of more than one type of biomolecules decays as sum of exponential decays. We used a prototype model with two exponential decays for definiteness. The shape of signal was specified by n(t), where n(t) dt was the number of detected photons in a small duration dt around t. The form of n(t) in the two exponential decays model was:

$$n(t)=S_0+S_1e^{-\lambda_1 t}+S_2e^{-\lambda_2 t} \qquad (1)$$

The model had five parameters S_0, λ_1, S_1, λ_2 and S_2. S_0 was background noise. It was a property of the measuring system and not of the signal. The decay rate and strength of two decays were (λ_1, S_1) and (λ_2, S_2). The decay having higher decay rate, taken to be λ_1, was called fast decay.

The second model was quantum model based on the following Hamiltonian of a frequency stable oscillator with explicit time (t) dependent frequency and mass terms:

$$H = \frac{p^2}{(1+\lambda t)^2} + \frac{1}{2}(1+\lambda t)^2 \omega^2 q^2 \qquad (2)$$

where p and q are the usual canonical conjugate variables of photon field of frequency ω and λ is the damping coefficient. The classical solution of the Hamiltonian is an oscillator with hyperbolically decaying amplitude and Popp and Li used it for describing decay shape of delayed luminescence signals [23]. The quantum photon field in a squeezed state evolving under this Hamiltonian remains in squeezed state though the energy of the field decreases continuously with decreasing rate. The expectation value n(t) of photon number in the field in adiabatic approximation has the following functional form [18] :

$$n(t) = B_0 + \frac{B_1}{(t+t_0)} + \frac{B_2}{(t+t_0)^2} \qquad (3)$$

B_i's represent calculated algebraic expressions depending on the squeezed state at some initial time and t_0 is λ^{-1} minus initial time. The quantum model uses eq. (3) for describing a biophoton signal using four signal specific decay parameters B_0, B_1, B_2 and t_0. The contribution of background noise (S_0 of the first model) is contained in B_0. The model is silent on bio-molecular basis of photon emission but it implicitly assumes that some entity in a definite but unknown state quantum emits biophoton signal. The entity is called quantum entity and it is a composite structure of all biomolecules implicated in biophoton emission. The decay parameters are properties of the quantum state of entity and are situation specific. They epitomize holistic and macroscopic response of a living object to a stimulation.

Five parameters of the first model and four parameters of the second model were estimated in each one of the 3600 versions of every response signal. The estimations checked the robustness of parameters of the two models. Only the parameters of the valid model would be robust and would have nearly same values in different versions of a signal. The validity of the first model would prove incoherent photon emission from specific biomolecules and would rule out the existence of quantum entity while the validity of the second model would prove the existence of many states of quantum entity and their association in responses to H_2O_2 stimulations.

3. Results and Discussions:

3.1 Stability of background noise: The background noise with close shutter (i.e. dark current) was very stable. It hardly changed throughout a day but it changed by a small amount on different days. The mean and standard deviation of background noise in measurements on five days in the span of 15 days were (0.26±0.03) counts/50ms. The noise with open shutter was higher than dark current and increased during the course of measurement. The mean and standard deviation of noise with open shutter in measurements on the above five days were (0.31±0.07) counts/50ms and (0.50±0.13) counts/50ms, respectively at the start and end of measurements on a day. The higher strength of background noise with open shutter and its increase during the course of measurements suggested that some object in the measuring area was emitting visible range photons and the emission increased during the course of measurement in every day. The object was found to be the pillow filled with sand used for resting the hand of subject. Human biophoton signals seemed capable of exciting sand pillow, which then emitted visible range photons for nearly 20 hours. The background noise became nearly equal to dark current when the pillow was removed. The pillow enhanced background noise slightly and the enhancement showed some correlation with the concentration of H_2O_2 used. The properties of signals were corrected three background noises-dark current and noise with shutter open at the start and end of measurements on every day. The corrected properties differed marginally in the three cases but their differences were not significant. The paper, therefore, presents the properties corrected for dark current or the background noise with shutter closed.

3.2 Properties of spontaneous biophoton signals: Spontaneous biophoton signals from dorsal and palm sides of left hand of the subject were measured seven times, three times on the first day and one time on four other days in a span of fortnight. The mean and standard deviation of signal strength in seven measurements were (0.32±.05) counts/50ms at the dorsal side and (0.60±0.07)counts/50ms at the palm side. These values indicate that the two anatomical sites emitted spontaneous biophoton signals of nearly unchanging but different strengths at least for a fortnight. The intercept of Fano Factor curve was 1.18 ±0.28 in signals from the dorsal side and 1.20 ±0.25 in signals from the palm side. The slope of Fano Factor curve was 0.021 ±0.29 in signals from the dorsal side and -0.014 ±0.074 in signals from the palm side. The magnitude of displacement $|\alpha|$ was 0.56 ±0.04 in signals from the dorsal side and 0.77 ±0.04 in signals from the palm side. The variation in $|\alpha|$ was smaller than that of signal strength. The three squeezed state parameters in fine grain version of all fourteen signals were of universal values. SSI was greater than 0.85 in eleven signals and less than 0.85 in three signals from the palm side. The value was 0.49, 0.60 and 0.84 indicating that the subject was, probably, a little tense or unwell on respective days of measurements and the signal from the palm side was more sensitive to ill health [22]. The observed probabilities differed from expected probabilities of quantum signal in

squeezed state and average difference between them in 14 biophoton signals was 0.005±0.001. We ascribe this small difference to the presence of a peripheral classical component that was too small to affect estimation. The presence of classical component was also indicated by the intercept of Fano Factor curve for the intercept in the absence of classical component would be nearly one. We further speculate that core component was stable while peripheral component varied with ongoing physiological changes.

3.3 Similar properties of 3min sections in response and biophoton signals: Table 1 presents six properties and the coefficient of second degree polynomial of Fano Factor curve of the sections of response signal from the palm side for 500mM concentration of H_2O_2 as well as of the spontaneous biophoton signal from the same site just before applying H_2O_2. This response signal was the most intense and its twenty one sections were measured, which were numbered from PR1 to PR21. P stands for palm side, R for response signal and numeric value for the number of section from the start of measurement. The spontaneous biophoton signal is identified as PSB. The table shows continuous decrease of signal strength and the rate of its decrease from PR1 to PR21. The signal strength in PR21 was nearly three times the signal strength of PSB. The measurement of subsequent sections were not made but signal strength became equal to PSB in less than 24 hours. The displacement $|\alpha|$ differed with the square of signal strength by a negligible amount and it showed similar decrease in the sections. The decay of signal strength in 3min was substantial in initial seven sections but was ignorable in other sections. The intercept of Fano Factor curve was 1.28 in PSB but became 1.07 in PR1. Larger signal strength and smaller intercept of Fano Factor curve in PR1 suggested that the portion of skin responded to H_2O_2 stimulation by enhancing core quantum component immediately. The immediate response was accompanied by reassessment that adjusted the value of damping coefficient. The strength of quantum component decreased with time because of damping. No such decrease occurred in the classical component. The relative contribution of classical to quantum component became comparable to the biophoton signal in last few sections and so did the intercept of Fano Factor curve. The subject did not feel irritation in the last few sections even though signal strength of response signal in them was more than three times the signal strength of PSB. The behaviour of intercept in other nine response signals and the perception of irritation by the subject was similar. Perhaps, intercept of Fano Factor curve, relative contribution of two components and the perception of irritation had some connections. The slope and the 2^{nd} coefficient of the Fano Factor curve were small and we could not discover any pattern in them. Table 1 gives their values only for completeness. Three squeezed state parameters had universal values in the fine grain version of signal in every section of response and biophoton signals. Coarse grain versions of some initial sections did not yield universal values for these parameters. The value of SSI in these sections was not equal to 1. Table 1 shows six such sections. The signal decayed

appreciably in these sections and vitiated the determination of photon count distribution. The measured photon count distribution did not correspond to average signal strength in such a section resulting in the erroneous estimation of squeezed state parameters, smaller SSI and larger SSR. Such sections were fewer in other response signals. The least intense response signal was from the dorsal side for 100mM concentration of H_2O_2 and its all sections yielded SSI=1. All sections of response signals on the three days when SSI of spontaneous biophoton signal was less than 0.85 yielded SSI=1. Correctly determined photon count distribution would have yielded SSI = 1 in the initial sections of response signals as well. As mentioned earlier SSI=1 implied dominance of core quantum component in response signals. The enhancement of quantum component was, perhaps, a way of invigorating or stimulating the quantum entity for mounting better defence against the chemical stress. Table 1 further shows that apart from signal strength and $|\alpha|$, all other properties had same or similar values in 21 sections of the response signal and in the spontaneous biophoton signal. Signal in the sections appeared to be high strength biophoton signals. Perhaps, response and biophoton signals had common nature, source and origin. The common source was, perhaps, a quantum entity.

Table 1 **Properties of 3min sections of a response signal:** Twenty one sections were measured in the response signal from the palm side for 500mM concentration of H_2O_2 and these were identified as PR1 to PR21. Only one section was measured in the spontaneous biophoton signal from the same site and it was identified as PSB. The table gives six properties and coefficient of the second degree polynomial of Fano Factor curve of these sections .The values of r, θ and ϕ were universal in the fine grain version of signal in these sections.

Section	Sig. Str.	Intercept	Slope	$\|\alpha\|$	SSI	Avg.SSR	2^{nd} Coeff.
PSB	0.72	1.29	0.05	0.85	0.91	7.26E-06	4.15E-03
PR1	14.49	1.07	6.29	3.81	0.3	3.53E-04	4.79E-03
PR2	11.63	1.04	0.05	3.41	0.4	1.59E-05	-3.33E-04
PR3	10.67	1.07	0.17	3.27	0.4	2.72E-04	-2.49E-02
PR4	10.09	0.98	0.45	3.18	0.5	7.84E-04	-1.54E-02
PR5	8.79	1.09	0.24	2.96	0.5	4.35E-05	1.44E-02
PR6	7.99	1.14	0.23	2.83	0.7	8.06E-06	-2.02E-02
PR7	7.17	1.14	0.04	2.68	0.7	4.95E-06	1.16E-02
PR8	6.25	1.02	0.06	2.50	0.9	1.32E-05	6.52E-03
PR9	5.53	1.14	0.15	2.35	0.9	7.38E-06	-6.50E-03

PR10	4.95	1.06	0.13	2.23	0.9	2.20E-05	1.15E-02
PR11	4.52	1.15	0.00	2.13	1	1.47E-05	6.66E-03
PR12	4.10	1.17	0.00	2.02	1	1.80E-05	1.07E-02
PR13	3.78	1.14	0.22	1.94	1	8.97E-06	-1.66E-02
PR14	3.40	1.39	0.13	1.84	1	3.81E-06	-1.33E-02
PR15	3.18	1.14	-0.21	1.78	0.91	6.83E-06	1.85E-02
PR16	3.06	1.00	-0.06	1.75	1	9.36E-06	9.01E-03
PR17	2.85	1.12	0.02	1.69	1	1.47E-05	8.10E-03
PR18	2.57	1.19	0.01	1.60	1	1.64E-05	9.67E-04
PR19	2.35	0.99	0.07	1.53	0.91	1.52E-05	-6.28E-03
PR20	2.27	1.22	-0.01	1.51	1	1.27E-05	-6.39E-03
PR21	2.11	0.97	-0.05	1.45	1	9.47E-06	1.83E-02

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3.4 Non-exponential decay character of response signals: The signal strength of a response signal decreased continuously with decreasing rate, which ruled out its exponential decay character. It was confirmed by determining the parameters of two exponential decays model in different versions of a response signal. All five parameters changed rapidly over large range with bin size of version. The parameters were version specific and could not be the properties of the signal. The decay parameters λ_1 and λ_2 differed considerably in different portions of any version of a signal, which again indicated that they are not properties of a version. They were also different in different response signals from the same site, which indicated that different concentrations of H_2O_2 elicited response from different biomolecules. The variations in the values of parameters ruled out exponential decay character of response signals. Eq. (1) of two exponential decays model was a mere parameterization bereft of insight.

3.5 Crossing of a pair of response signals: The initial strength of response signal from a site for higher concentration of H_2O_2 was usually higher. An exception occurred in signals for the concentrations of 400mM and 500mM. The initial signal strength of the response signal for 400mM was higher than for 500mM. The initial rate of decrease of strength was also higher in the response signal for 400mM. Higher initial strength and higher rate of decrease of strength in the response signal of 400mM made it to cross the response signal for 500mM. The crossing

occurred in response signals both palm and dorsal sides for these concentrations. The crossing highlighted the complexity of response signal and ruled out its description in the semi-classical framework.

3.6 Robustness of the parameters of quantum model and extraction of holistic properties: The values of three parameters B_0, B_1 and t_0 of the quantum model were nearly same in different versions and durations of a respond signal but the value of B_2 changed with version and duration. The three parameters were robust to change in bin size and duration of signal in all response signals. Robustness was observed for bin size in the range (50ms - 90s) and duration in the range (30min -1hr). The parameter B_2 was not robust and it fluctuated in a large range, perhaps, because its contribution to n(0) was too small to permit its accurate determination. The contribution was less than 3% in every portion of all response signals. The contribution of B_0 was also too small and of little significance but it was robust. The estimated values of four parameters in the fine grain version of ten response signals are given in table 2.

Table 2 Decay properties of response signals in the quantum model: The table presents four decay parameters in the quantum model of ten response signals. The fine grain version of the signals were used in the estimations. The results for the signals for five concentrations of H_2O_2 are grouped separately for the two sides of the hand. The contribution of B_0 in strong signals is very small and is ill determined. The contributions of the three terms to n(0) are B_0, B_1/t_0 and B_2/t_0^2

Concentration of H_2O_2 (mM)	B_1(counts)	t_0(s)	B_2(counts.s)	B_0(counts/s)
Dorsal side signals				
100	4759	43.84	4624	7.01
200	6622	97.37	19985	17.75
300	30292	315.95	21284	15.06
400	108170	734.08	57506	0.00
500	261640	2205.30	200450	0.00
Palm side signals				
100	17599	72.55	23605	19.84
200	55032	251.61	37899	9.12
300	60434	208.82	46430	14.46
400	196080	441.26	56289	0.00
500	265500	783.49	104540	0.00

The parameters given in the table are measured values of four holistic properties of respective signals. The parameters Bi's specify the strength of three different terms determining the shape of signal. B_1 was much larger and its contribution was dominant in every response signal. The table shows the dominance of the contribution of B_1. The dominance allows one to ignore the contribution of other two terms for obtaining two parameter description of response signals. The decay of response signal in this description is hyperbolic and the parameters B1 and t_0 used in the description are robust. Fig.1 and Fig.2, respectively, depict their estimated values in different versions of all ten response signals. The bin size of these versions varied from 50ms to 3min. The parameters hardly changed from 50ms to 100s. They were robust in versions of higher bin sizes as well, particularly in signals measured for longer duration e.g. up to bin size of 200s in the longest duration response signal for 500mM concentration.

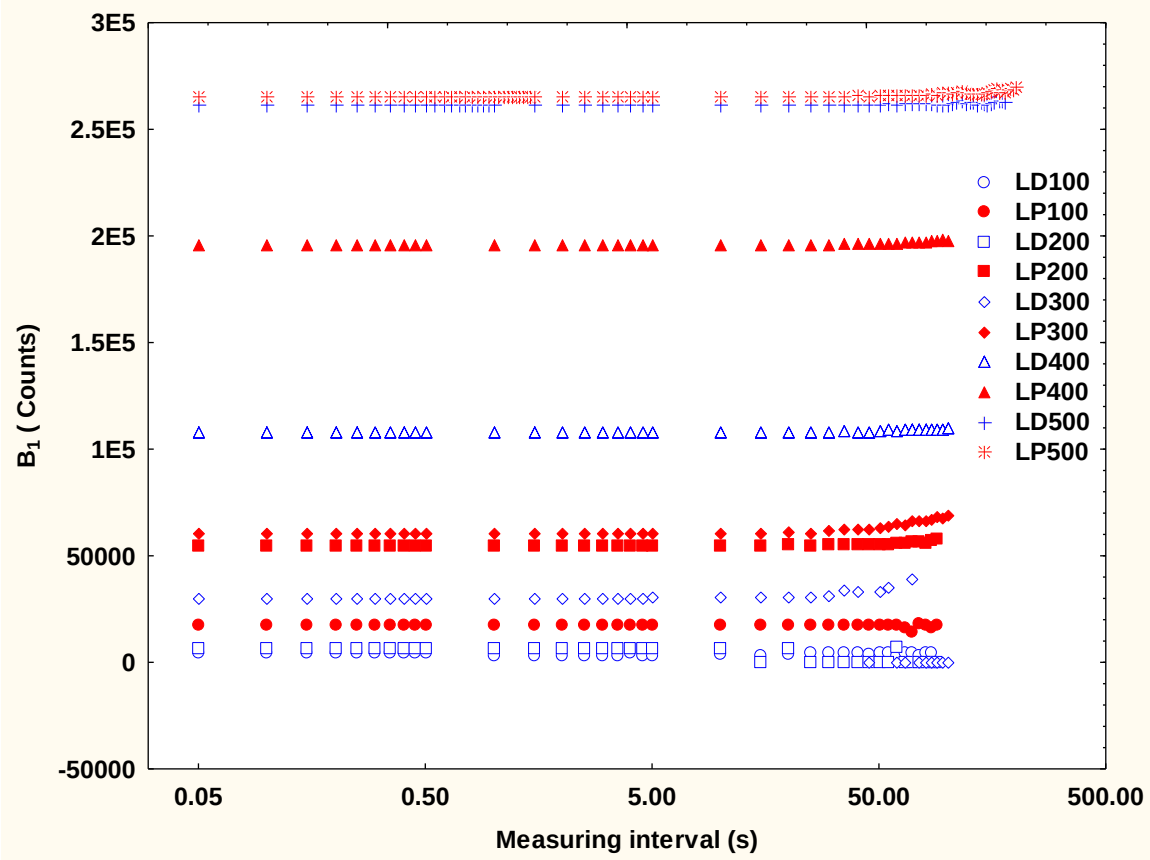

Figure 1 Robustness of the parameter B_1 to change in measuring interval: The parameter B_1 estimated in different versions is plotted against the measuring interval of version for ten response signals. The legends in the figure specify response signals by two letters of alphabet and three numbers. The first letter is L for left hand, the second letter is D or P for dorsal or for palm side and three numbers give concentration of H_2O_2 in mM.

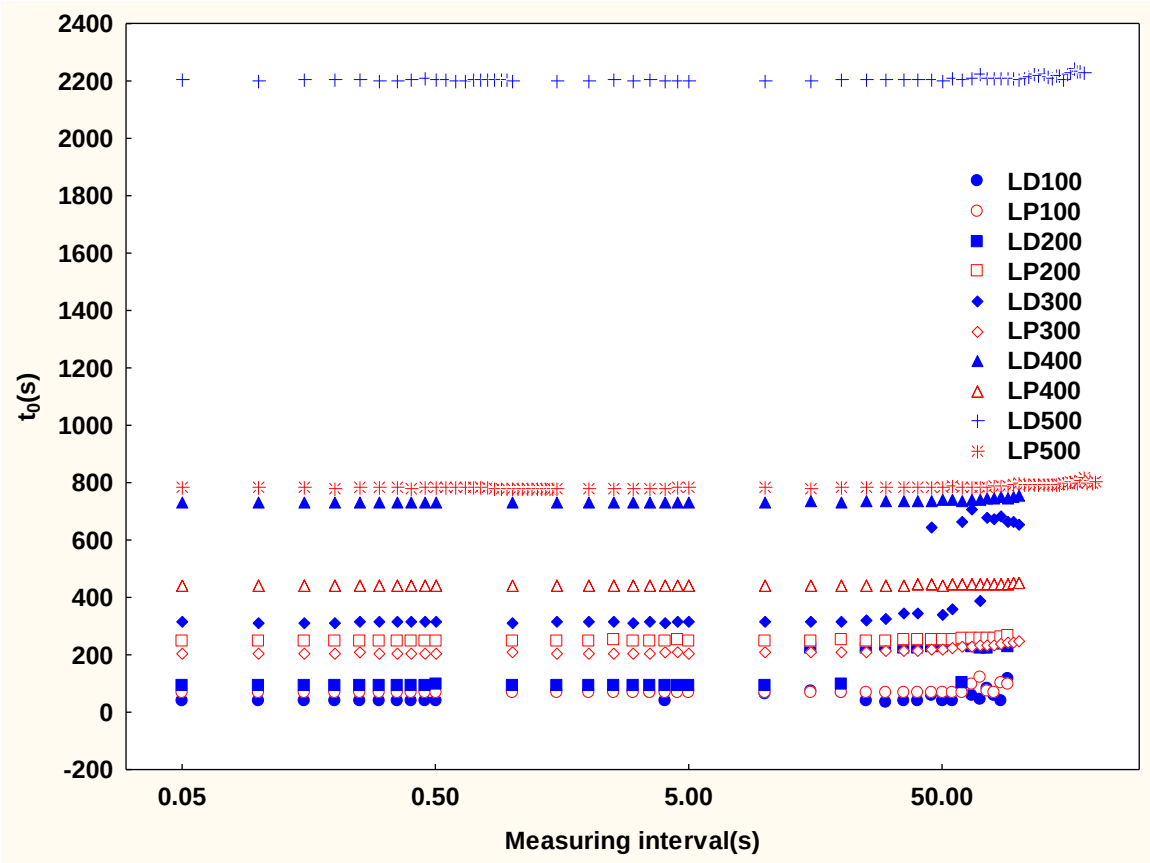

Figure 2 Robustness of the parameter t_0 to change in measuring interval: The parameter t_0 estimated in different versions is plotted against the measuring interval of version for ten response signals. The legends in the figure specify response signals by two letters of alphabet and three numbers. The first letter is L for left hand, the second letter is D or P for dorsal or for palm side and three numbers give concentration of H_2O_2 in mM.

This signal was measured for 63min. Non robustness of parameters in versions of higher bin size of signals measured for smaller duration is, perhaps, a consequence of erroneous estimation of parameters from only a few data points e.g. the 60s version of response signal for 100mM from the dorsal side had only nine points and these points could not correctly estimate four parameters. The observed robustness of parameters was impressive and sufficient for validating the quantum model. The validation determined additional holistic properties of human hands. It is further pointed out that SSR in the quantum model was invariably smaller than in the two exponential decays model, which also indicated the quality fit to be better in the quantum model.

The two parameters description attributes crossing of response signals to nonlinear dependence of B_1 and t_0 on the concentration of H_2O_2. Both increase nonlinearly with concentration but their dependencies are different. The increase of t_0 with concentration made the response signal of

higher concentration flatter. The initial strength n(0) of a signal was determined not by B_1 alone but by a combination of B_1 and t_0. The different dependencies on concentration of the two parameters led to situations in which a response signal of higher concentration had lower initial strength n(0) but flatter decay. This caused signals of higher and lower concentrations to cross at some times. We observed crossing of response signals of 400mM and 500mM concentrations at both sides. The crossing of signals is difficult to comprehend in the semi- classical framework. It brings out the complexity in photon emission of response signals.

3.7 Coherence or strong coupling of photon modes in response and biophoton signals: The robustness of squeezed state parameters and decay parameters established the applicability of the expressions of probabilities in a squeezed state [20] and the shape of signal in an evolving squeezed state [18]. These expressions were valid for single mode photon field. The broadband detector counted photons of many modes. Why were the expressions of single mode applicable in multimode biophoton and response signals? The universal values of three squeezed state parameters suggested a possible reason. One possible solution is to demand that photons of every mode were in squeezed states with universal values of three squeezed state parameters and same damping coefficient or t_0 in every evolving squeezed state The solution is prescription of coherence or strongly coupling of photon modes, so that dependence of photon count distribution on mode strength was the same for all modes.

3.8 Analyses of signals in other systems: The spontaneous biophoton signals have been measured at multiple sites in more than hundred human subjects and most of them had a core quantum component in squeezed state with universal values of three squeezed state parameters. Response signals were measured in two other human subjects for a few concentrations of H_2O_2. The decay parameters of these response signals in the quantum model were robust while their 3 min sections were in the expected squeezed states. The robustness of the decay parameters in the quantum model was checked in a few delayed luminescence signals of leaves. The decay parameters were not robust but varied in narrow ranges. The 3 min sections of these signals were not in squeezed states. Perhaps, the quantum entity of a leaf detached from the intact plant was stressed and not in a pure squeezed state.

4. Conclusions:

The important inferences are summarized below:

4.1 Two small portions of the skin at the palm and dorsal sides of the left hand of a human subject continuously emitted spontaneous biophoton signals at least for a fortnight. The biophoton signals from the two sites were detected on five days in this period and their nine properties were determined. Three properties (three squeezed state parameters) were observed

to be same in all ten signals, two properties (signal strength and $|\alpha|$) were nearly unchanging in signals from a site and four properties (intercept and slope of Fano Factor curve, SSI and SSR) changed in small ranges in different signals.

4.2 The intercept of Fano Factor curve was much higher than expected in pure squeezed state signal. It suggested that biophoton signals had two components, core quantum component in squeezed state and classical peripheral component.

4.3 The response signals from two sites were measured for five concentrations. The response signals for 500mM and 400mM concentrations crossed each other. The crossing occurred at both sites in response signals of these concentrations. Crossing indicated complexity and non-classical nature of response.

4.4 All properties except signal strength and $|\alpha|$ were same or similar in a 3min section of response and spontaneous biophoton signals. Every section of response signal was a high strength biophoton signal with larger core quantum component.

4.5 Response signals lacked exponential decay character. The decay parameters of every response signal in the two exponential decays model were not robust and their values were different in different measurements and portions of the signal. They were not related to the properties of response signal and biomolecules.

4.6 Response signals were akin to a quantum signal. Three decay parameters of every response signal in the quantum model were robust and their values were same in different measurements of every response signal.

4.7 The decay of response signal was essentially hyperbolic. It was correctly described by two parameters B_1 and t_0, which increased non-linearly with concentration of H_2O_2.

4.8 The same quantum entity was, probably, involved in emitting biophoton and response signals from human skin.

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Appendix 1

Brief introduction to squeezed states and their relevance for understanding biophoton signals

Quantum Field Theory describes photons (and also electrons or any other material particles) by a field, whose complete description requires specifying state vector of the photon field and the Hamiltonian governing the dynamical evolution of state vector. The state vector is usually specified in occupation number space and its basis vectors are number states of free photon field. The number states are connected by creation and annihilation operators. Restricting for simplicity to single photon mode of frequency ω, the annihilation and creation operators are (a, a^+). They satisfy the commutation relations [a, a^+] =1, [a, a^+] =0 and [a, a] =0. The number operator is a^+a and its eigen states are number states. The Hamiltonian governing the dynamics of free photon field $H = \hbar\omega(a^+a + \frac{1}{2})$. The basis vectors in the occupation number space are $\{|n\rangle, n = 0,1 \ldots\}$, where n is the eigenvalue of the number operator. The ground state $|0\rangle$ of the free field is the vacuum state and has zero value of a^+a. A scintillation counter is used for counting the number of photons of free field entering the detection area in a duration Δ or bin of size Δ. Repeated measurements of photon numbers in contiguous bins of a biophoton signal show fluctuations in photon number, which implies that the biophoton field is not an eigen state of number operator of free photon field.

The quantum state of interacting photon field of a specific type of interaction is determined by a trick, in which interacting photon field is described by a free quasi photon field governed by the Hamiltonian $H_{quasi} = \hbar\omega(b^+b + \frac{1}{2})$, where ($b$, b^+) are annihilation and creation operator of the quasi-photon field and they satisfy the commutation relations [b, b^+] =0, [b, b] =0 and [b^+, b^+] =0. The problem is solvable and the basis vectors of the solutions are number states of the quasi photon field$\{|n, quasi\rangle, n = 0,1 \ldots\}$. The connection between free photon and quasi-photon fields is established by assuming that the operators b and a are connected by a unitary transformation. The assumption restricts permissible interaction. The most general commutation relations preserving unitary transformation [20] is

$$b = D(\alpha)S(\xi)aS^+(\xi)D^+(\alpha)\ , \qquad \text{(A1)}$$

where D (α) and S (ξ) are given by:

$$D(\alpha) = exp(\alpha a^+ - \alpha^* a)\ ;\ S(\xi) = exp\left[\frac{1}{2}(\xi^* a^2 - \xi a^{+2})\right] \qquad \text{(A2)}$$

They contain two complex parameters α and ξ or equivalently four real parameters α =|α| exp(iφ) and ξ= r exp(iθ). Similar unitary transformations involving a3 or higher powers are reducible to D (α) and S (ξ). D (α) and S (ξ) are also commutation-relations-preserving unitary transformations. The operator D(α) displaces the creation operator a by –α

$$D(\alpha)aD^+(\alpha) = a\text{-}\alpha \qquad \text{(A3)}$$

and is called displacement operator. The operator S (ξ) rotates (a, a^+) in the two dimension space by an angle θ and squeezes a circle in this space into an ellipse of same area I.e.

$$S\ (\xi)\ aS^+(\xi) = (\ a\ coshr + a^+ \exp(i\theta)\ sinhr) \qquad \text{(A4)}$$

S (ξ) is called squeezing operator. The Eq. (A3-A4) allow us to express H_{quasi} in terms of free field operators, which explicitly brings out the interaction term of H_{quasi}. The basis vectors of quasi photon field are related to the basis vectors of free field by the unitary transformation:

$$|n, quasi\rangle = D(\alpha)S(\xi)|n\rangle \quad \text{(A5)}$$

Eq. (A5) provides exact and non-perturbative solutions of the interacting Hamiltonian H_{quasi}. In particular, the ground state of the interacting Hamiltonian is the vacuum state of quasi field $|0, quasi\rangle = D(\alpha)S(\xi)|0\rangle$. It is called squeezed state of photon and is depicted by $|\alpha, \xi >$. The operator *b* annihilates this state. On operating both sides of Eq. (A5) for n=0 with *b* one demonstrates that squeezed state is an eigen state of some linear combination of free field operators *a* and a^+. Squeezed state corresponding to ξ=0 (i.e. r=0 and θ=0) is called coherent state, which is an eigen state of the annihilation operator *a*. The properties of photon signal in a squeezed state are calculated by following standard method. The calculated expressions of average number of photons detected in a bin (or signal strength) $k_{sig}(cal)$ and probabilities P_{sig}^n (*cal*) of detecting n photons in a bin are given by

$$\mathrm{k_{sig}}(cal) = |\alpha|^2 + \sinh^2 r \ . \quad \text{(A6)}$$

$$P_{sig}^n(cal) = \left|\langle n | \alpha, \xi\rangle\right|^2 \quad \text{(A7)}$$

,with overlap of squeezed and number states given by

$$\langle \mathrm{n}|\alpha,\xi\rangle = \frac{1}{\sqrt{\mathrm{n!}\cosh \mathrm{r}}}\left[\frac{1}{2}\exp(\mathrm{i}\theta)\tanh \mathrm{r}\right]^{\frac{\mathrm{n}}{2}} \exp\left[-\frac{1}{2}\left(|\alpha|^2 + \alpha^{*2}\exp(\mathrm{i}\theta)\tanh \mathrm{r}\right)\right] \times \mathrm{H_n}\left[\frac{\alpha + \alpha^{*}\exp(\mathrm{i}\theta)\tanh \mathrm{r}}{(2\exp(\mathrm{i}\theta)\tanh \mathrm{r})^{\frac{1}{2}}}\right] \quad \text{(A8)}$$

where H_n is Hermite polynomial of degree n. The Eq. (A6-A8) are valid in all versions of a signal i.e. for measurements with bins of any size.

Squeezed state nature of a spontaneous biophoton signal is established in two steps. The first step determines the parameters of squeezed from signal strength and photon count distribution in the time series of a signal. The second step validates the squeezed state parameters by showing their robustness to change in bin size. Since the total number of photons detected in a time series is well determined and is the same in all versions of a time series for different bin sizes, k_{sig}(*cal*) is equated to the average number of photons detected in a bin in the time series, called k_{sig}(*obs*), and then Eq. (A6) is used as a constraint. The constraint reduces the number of independent squeezed state parameters to three i.e. r, θ and φ, which were estimated by optimizing the sum of the squares of the difference between observed and calculated probabilities of photon count distribution in the manner described in the paper. The procedure succeeds in establishing squeezed state nature and in determining quantum state of many spontaneously emitted human biophoton signals. The procedure also determines the effective Hamiltonian H_{quasi} and implies long range order in the biomolecules implicated in biophoton emission. The universality of squeezed state parameters is probably indicative of similar cellular environment.

The above procedure also succeeds in determining ground state of Hamiltonian with some types of explicit time dependence [15]. The technique was used in determining the time dependence of signal strength in the ground state of the Hamiltonian suggested by Popp and Li. The expectation value of the photon number operator in the ground state was calculated and its calculated expression contained many terms oscillating with mode frequency. The oscillating terms were replaced by their average values over a mode cycle. The averaging procedure amounted to making adiabatic approximation. The averaging simplified the calculated expression, which was used for describing the shape of delayed luminescence and response signals. The averaging ruled out the determination of quantum state of signal and effective Hamiltonian. Robustness of decay parameters merely checked the validity of the parametrization of shape. The Hamiltonian suggested by Popp and Li [23] is not unique. Many other Hamiltonians also have frequency stable classical solutions. This procedure can also determine the quantum ground state of these Hamiltonians. The shape differs marginally in the ground state of different Hamiltonians.

Appendix 2: Comments and Responses

Reviewer 1:

I would be very interested to know Matti's comments on the paper (Popp and Li) in which the squeezed state model was proposed: is this a feasible mechanism?

Rajendra Bajpai:

I have two points to make on Popp and Li's paper:

1. Popp and Li paper is partly correct. It has a fatal mistake. Its classical solution is correct but its quantum version is incorrect. They made a fatal mistake in speculating that the unitary evolution operator U(t) should satisfy for two arbitrary time intervals t_1 and t_2 the group property $U(t_1).U(t_2)=U((t_1+t_2)/2)$.

2. The suggested Hamiltonian is not unique but simplest. There are many possible time dependent frequency stable Hamiltonians and their time dependencies are different. They give rise to slightly different shapes in quantum calculations made under adiabatic approximation. The simplest Hamiltonian gives the basic shape.

Prof. Matti Pitkanen's Comments are interesting and we are grateful that he agreed for their incorporation in the paper as an Appendix entitled " **Do bio-photons originate from the decay of squeezed dark photons?"** Prof. Pitkanen offers a possibility for the origin of biophotons. We refrained from making any speculation in this regard in the paper. If forced to speculate, we shall

follow G. Preparata(QED Coherence in Matter, World Scientific, 1995) and suggest that certain combination of organic matter at specific density and temperature permit non-perturbative ground state that emits squeezed state photons. The incessant emission of photons makes the system metastable and dependent on the adequate provision of energy. Metastability confers finite lifetime while inadequate supply of energy confers diseased state to a living system.

Reviewer 2:

[...] It would be helpful for it to discuss the software used with PMT, temp cooled, and what LLD/HLD discrimination values were used. What type of dark room, etc. Most papers omit these details. Getting good signal to noise ratios is one of the challenges in this type of experiment and how it is done so such experiments could be repeated is valuable information.

Bajpai has authored a few articles in Phys Ltrs r/e squeezed states and many people have studied the skin for several years. Without going back to study that history it is difficult to comment, however squeeze states are characterized by the lower limit of Heisenberg's inequality being an equality i.e. dx*dp =h/4pi which is characteristic of ground states. It is not clear to me why the identification of such sates is significant. Quantum effects are always present when light quanta or photon counts, are involved so the fact that biological systems emit at optical frequencies in quantities above the thermal black body radiation in response to various chemical stimulation is significant. What squeeze states of those emitters might tell us is not clear to me.

Rajendra Bajpai:

The experimental details were mentioned in old papers and conference and summer school proceedings edited and authored by Popp. The important step was the selection of PMT tube. The manufacturer puts special type in parentheses to indicate that these tubes have exceptionally low noise. The PMT tube was cooled to -25^0C and the measurements were made after a few hours of cooling and getting stable dark counts. The dark room was a small room with minimum of furnishing. Light was not switched on for many hours before measurements. The software was written by a research student few years earlier but was not crucial for a few other system fabricated for Popp as well as for Ronald Van Wijk give similar results and use Labview. The LLD/HLD discrimination values were fixed by the technical team by calibrating with the help of a standard radioactive source. The technical team used to check the back ground noise with open and closed shutter in the morning before allowing the use of the system for measurements

1. Squeezed state is incidental. The significant aspect is quantum nature of photon signal inferred from photon count distribution in a macroscopic duration, which implies long time statistical correlation of photon emitting processes. Since a quantum photon signal is emitted only by a quantum system, quantum biophoton signal implies the existence of a quantum entity for macroscopic time. All biomolecules implicated in biophoton emission are constituents of the quantum entity. Squeezed state is significant for a model of living system and for its capability to carry much larger information. The model envisages squeezed state photon field as a binding field creating long range order of living system through spontaneous breakdown of some symmetry. Squeezed state confers diversity as well. These are speculative ideas which we hope to submit in June 2015 issue.

2. The system of retina is interesting and give slightly different information. It a single system and is relatively cleaner but it is a part of whole system. My experience with parts of the plants suggests that quantum state of biophoton signal is different in part and whole plant. We need to know at which state of development the squeezed state emerges. It will be interesting to measure biophoton emission in embryonic stem cells.

Reviewer 1:

The basic thought seems to be [that] life has a quantum biophoton signature [...]. The authors allow us only two choices: a two-term sum of exponentials or a sum of 2 inverse terms from an assumed Hamiltonian. The criterion of choice is the **consistency** of the coefficients for these two models. Why restrict it to only two exponentials, while there could theoretically be any number? I suspect that a Hamiltonian could be written for any arbitrary form of time decay (though I would not like to do it): the authors do not give any physical justification for the particular Hamilton they use, nor do they cite an experimental example. How many exponential terms are needed to approximate the Hamiltonian-based equation? I would have thought the primary criterion would be goodness of fit to the non-linear models: this allows not just overall testing but of the individual terms too. (This is of interest since the second inverse term may not be significant, leaving a rectangular hyperbola over.)

The system employed (the hand of a single person) is not a convenient one for experiment e.g. to test for life-dependency it would be necessary to look before and after cutting it off! On reading a little on bioluminescence I find that much of this is due enzyme-catalysed oxidation of luciferin, which is found in many distantly related species (this is only one possibility). I don't know if the luciferin reaction produces an exponential decay, though it does seem reasonable this is so. What happens if a tiny bit of luciferin is added to a (hand) tissue homogenate? This potentially gives a whole bunch of energy levels, each of which yields an exponential. It seems odd to me that there is no mention made of luciferin type reactions at all.

Rajendra Bajpai:

Biophoton signal is a signature of ‘life’ and it measures holistic attributes of the emitter through its shape and photon count distribution exhibiting time coordination. Shape can be modeled in the semi-classical and quantum frameworks but photon count distribution only in the quantum framework. In the semi classical framework, shape is modeled by sum of exponential terms. The parameters of model are identified as strength and decay constant. They are properties of the signal related to the properties of biomolecules. The signal properties have to be same in its all portions and versions. Bio-molecular connection implies same decay constants in response signals of different concentrations of H_2O_2 from a site and stability of background noise implies same S_0 in all response signals. The model in the semi-classical framework fails in both counts. Three parameters of the model for the most intense signal are depicted in Fig.A1 below:

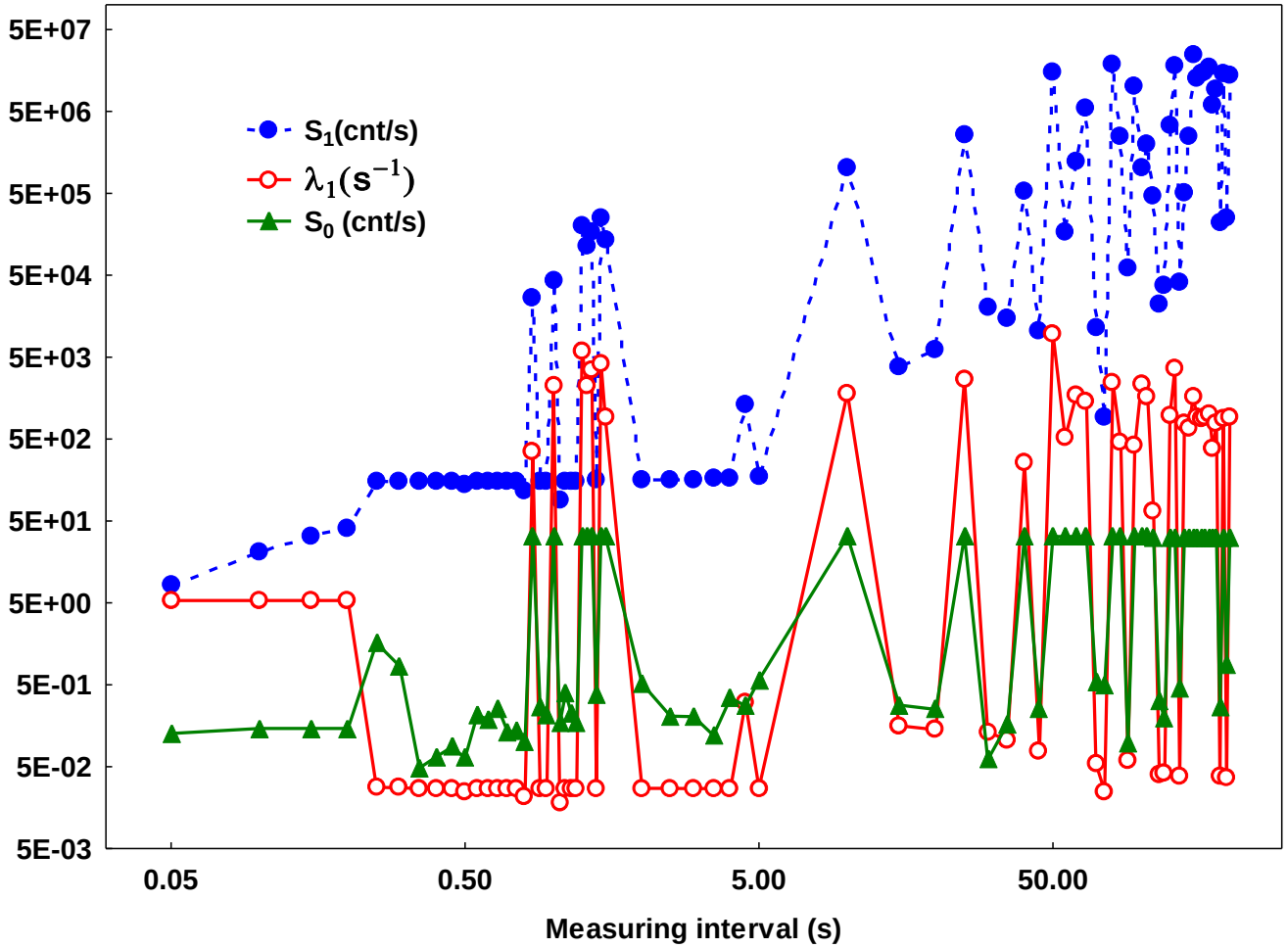

Fig.A1: **Absence of Exponential decay Character in a Response Signal:** The parameters (S_1, λ_1 and S_0) of the two exponential model in different versions of the response signal for 500mM concentration of H2O2 from the palm side of the hand. The versions correspond to different measuring intervals.

The other parameters S_1 and λ_1 of the model change more rapidly and in larger ranges with measuring interval. The parameters of all ten signals change similarly with measuring interval. The inclusion of more exponential decay terms will not alter this behavior and the parameters will remain non- robust.

The quantum framework does not restrict the form of Hamiltonian. One builds a model in the framework by starting with a general frequency stable damped harmonic oscillator solution in the form $q = \frac{q_0}{f(t)}\sin(\omega t + \varphi)$ and then constructing Hamiltonian yielding the classical solution. Different forms of *f(t)* give rise to different Hamiltonians whose classical solutions decay differently. The quantum solutions of these Hamiltonians can also be obtained by a non-perturbative method provided *f(t)* satisfy some reasonable conditions e.g. *f(t)* should be non- zero for positive t. The ground state is an evolving squeezed state in the quantum solution. The time dependence of the number of photons in the ground state *n(t)* in adiabatic approximation is given by

$$n(t) = C_0 + C_1 \frac{f(t)'}{f(t)} + C_3 \left(\frac{f(t)'}{f(t)}\right)^2$$

where C_0, C_1 and C_2 are state specific constants and prime denotes time derivative. The time dependence of *n(t)* is very similar the solutions of different Hamiltonians. Our quantum model uses the simplest and most parsimonious choice f*(t)= 1+$\lambda_0 t$* . It was a fortuitous choice. The quantum model emanating from the choice was validated by the robustness of its decay and squeezed state parameters. Squeezed state parameters were determined from photon count distribution in different 3min regions of response signals. They provided clinching evidence of the validity of the quantum model. The semi-classical model has no explanation for photon count distribution. The semi classical model attributes photon count distribution to unpredictable disturbances and hence, of no significance.

Human hand is the most convenient system for studying spontaneous biophoton emission. The system is clean and without a substrate. It can be considered a stable system for a fortnight. Any change occurring in it is felt and reported by the subject. In addition, medical sciences can also detect and corroborate the change. The subject does not experience discomfort during measurements. Palm and dorsal sides of hand emit biophoton signals of different strengths, so that two different biophoton signals emitted by a subject are available for investigations. Measurement of biophoton signals in convalescing subjects (e.g. a patient of multiple sclerosis or sleep deprived subjects) indicates a connection between squeezed state nature of biophoton signal and holistic features like health and stress. The homogenate of human tissue is a disrupted system and is unsuitable for studying holistic features of live subject. It is not expected to emit quantum photon signal in squeezed state.

A solution of human tissue on adding luciferin as well as a sample of human blood on adding heparin emit decaying visible range photon signal. The emission in both cases is based on local chemical reactions. Any mechanism based only on local chemical reaction cannot explain observed time coordination in biophoton emission, particularly, the emission of visible range photon signal of constant strength for a fortnight. Photon signals emanating from local chemical reactions have to decay because of the depletion of reactant chemicals and any number of decaying photon signals cannot give rise to a signal of constant strength. Beside, human biological fluids have been studied extensively and no mechanism for the production of luciferin compounds has been found so far. These issues were discussed repeatedly in conferences on biophotons in eighties and nineties of the last century and in summer schools of International Institutes of Biophysics, Neuss, Germany in the first decade of current century. The general consensus has been that independent local chemical reactions can account only for a part of the observed photon signal but a major part and regulation (i.e. time coordination) in the emission remain unexplained.