# Biophoton Emission from Lichens

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Living objects continuously emit photons of almost constant flux though of ultra weak strength [1]. The spectrum of emitted photons is broadband and lies mainly in the visible range. Even this weak intensity of visible range photons is much higher than expected in blackbody radiation. The emission requires up conversion of biochemical energy ~ 0.01 eV available in (ATP-ADP) transition or its variants into visible range photons of energy ~ 3 eV. No universal mechanism for such up conversion has been discovered so far. The emitted photon signal has unusual features and shows long time patterns. The signal appears situation specific and show sensitivity to many factors. A suffix bio is added to the signal and photons for indicating unusual features and biological origin. A few seconds exposure of a live object to normal laboratory light stimulate the object to emit an enhanced biophoton flux for a while. The enhanced flux decays to pre stimulation level but is observable for a time much longer time than that expected in fluorescence. The decay is non exponential in character. The spectrum and other unusual features of the decaying signal are similar to the non-decaying pre stimulation signal. As a result, it is also called biophoton signal though an adjective light induced is added to it and spontaneous to non-decaying signals. The determination of the strength and shape are problematic in a non exponential decay. One has to define suitable measures. A popular and pragmatic measure of the strength is the photon flux detected in the first measuring interval immediately after exposure to light. But there is no consensus about the measure of shape. There is a measure for duration of decay; it is defined as the time in which photon flux drops to 10% of its initial value. The strength and duration in biophoton signals vary considerably in different systems. Fig.1 gives an artist rendering of a typical biophoton signal that summarizes universal features. The maximum duration of decay of ~ 200s occurs in signals of photo synthetic systems. The strength of these signals is also higher by nearly two orders of magnitude. Because of high strength and long duration the decaying signal is detectable even with less sensitive detectors. The phenomenon in fact was discovered in photosynthetic systems and was called delayed luminescence. The name still persists but is gradually replaced by light induced biophoton emission.

Biophoton signal is identified by its characteristic shape- an initial decay region of non-exponential character followed by a long non decaying region. Various spectral decompositions of a biophoton signal obtained by filters also have similar shapes. The stimulations of a live object with light of different spectral compositions produce signals of similar shape. The absence of exponential decay in a signal and in its spectral decompositions is hard to comprehend as it does not occur in the conventional framework of photon emission. Its description needs some new assumptions. If we assume that biophoton signal is a photon signal in a pure quantum state whose dynamics is given by the frequency stable damped harmonic oscillator with time dependent damping and mass terms, then we can explain the shape and many other equally unusual features of biophoton signals [2]. The assumption ascribes dynamics to the shape. The shape indicates that the photon flux n(t) detected t seconds after stimulation is changing with t. It has been calculated and the result is the following expression:

$$n(t) = B_0 + \frac{B_1}{(t + t_0)} + \frac{B}{(t + t_0)^2} \qquad (1)$$

$B_0$, $B_1$, $B_2$ and $t_0$ are parameters of the model, which contain information about the state of the emitting system and mechanism of emission. These are called decay parameters. Eq.(1) provides a new framework for analyzing biophoton signals. The state dependence of the decay parameters makes a biophoton signal situation specific. Different values of parameters give rise to a vast diversity of permissible shapes to represent every state of all live objects. Biophoton signals can pick up changes in the state of live objects. The state of a live object may change due to a change in a physiological or environmental factor. Biophoton signal is influenced by both types of factors and hence can be used for measuring them [3]. The four decay parameters change differently, so that the influence of change in different factors is observed in different regions of biophoton signals. One has to find out proper region for measuring a specific factor and a method of calibration. It is desirable to have some combination of parameters that is sensitive to change in many factors and is easily measurable. Luckily, earlier mentioned strength of the signal is such a combination of decay parameters that is measurable

in less than a second by the number of counts detected in the first bin immediately after light exposure and is very sensitive to many exogenous factors. Strength is essentially determined by the sum of parameters $B_0$, $B_1$ and $B_2$. It is not discriminating enough to measure the influence of endogenous factors e.g. germination capacity of seeds, freshness of food material, etc. The parameters $t_0$ and $B_1/B_2$ appear more suitable for these measurements. There are many published results based on the measurement of strength and its sensitivity [1]. We shall not recall them but shall present examples that demonstrate the sensitivity of other of parameters to endogenous and exogenous factors.

Our first example is a light induced biophoton signal observed over seven orders of time scale in the range (1ms-11111s) using 5 bin sizes. The measuring system has been described many times in the past [4]. A sample of lichen species *Parmelina.wallichiana* collected nearly 3 months earlier emitted this signal. A fit to the observed signal using Eq.(1) was obtained by least square minimization. The observed signal, fit to the observed signal and calculated values of the parameters are depicted in Fig.2. The figure demonstrates the efficacy of Eq.(1) in reproducing average photon flux up to 7 orders of time scale. The signal becomes almost non-decaying after 10m and fluctuations occur at every bin size. We have observed fluctuations in bin sizes ranging from 1ms to 100s in many samples of 12 species of lichens [5-6]. The biophoton signal of a lichen sample is very stable that keeps the strength and shape unaltered for many days, perhaps, because of the negligible growth and decay of lichens in a few days. A lichen sample can check the stability of a measuring system and can be used as a control for other measurements. The stability of biophoton signals of plant based materials is high, so that decay region can be measured many times and fluctuations of the non-decaying region can be measured over a longer period.

Live object responds quickly to environmental changes through its biophoton signal. The f decaying and non decaying regions of the signal respond differently. The different responses arise naturally from different behaviours of decay parameters in the quantum model. It is easy to change the temperature of the environment. Consequently, the change in biophoton signals caused by changing the temperature has been studied in many systems. The effect in the decay region is pronounced. The effect in non-decaying region is mild but measurable. It has been measured with less sensitive equipment in Valencia [7] by the Bioreply group in lentil seedlings. Their measurements for 1500s of non decaying region at $22^0$C, $37^0$C and $45^0$C are depicted in Fig3. The measurements were made after leaving the lentil seedling in the dark for 15m. The signal is most intense at $37^0$C. Since metabolic activities are also most intense at $37^0$C, the figure brings out a connection between metabolic activities and strength of biophoton signal. The figure also gives another characteristic of a biophoton signal namely, its Q value (= Variance/Mean -1). The Q value indicates whether fluctuations are random or contain some inherent structure. Different Q values imply different structures. The biophoton signal has different structures at three temperatures, which perhaps occurs due to different metabolic activities. The high photon flux makes it difficult to characterize these structures in the quantum model. A good characterization requires the photon flux to lie in the range (3-15) counts/ bin.

The next example demonstrates the response of a biophoton signal to ongoing physiological changes in a sample of lichen *Xanthoria.parietina*. The physiological changes were triggered by the detachment of the sample along with the substrate from its host that severed the symbiotic relationship of lichen with the host. The initial decay region for 100s was measured in its light induced signal after every hour. The signal changed both in its strength and shape with time. The strength changed only for 10-15m after detachment but the shape continued to change for nearly 2h. The signal became stable after two hours and remained so for next five hours. The strength started decreasing after 7h but shape did not change. The strength continued to decrease for next 8h and then stabilized to a much lower value. The decrease in strength is attributed to evaporation of water from the sample and it continued till the sample became almost dry. A few drops of water were added to dry sample after 17h of detachment. The signal strength immediately increased to the stable value observed earlier i.e. 2h after detachment. No further measurements of shape and strength were made in this sample, but in other samples we have observed decrease and increase in the strength of the signal with evaporation and wetting for 2-3 cycles. The change in shape during first two hours of detachment is a new result. The signals of same strength but differing shapes indicate ongoing changes in the physiological state of the sample. The biophoton signals start from nearly same photon flux but decay differently. The differences are small in the first 50s but became substantial afterwards for a few minutes. It appears that detachment triggers metabolic processes and these processes continued for nearly an hour in this sample. The physiological state of the sample kept on changing and so the shape of the signals. The region from 50s to 100s of four representative biophoton signals is depicted in Fig.4. The signal at 10m was our first measurement after detachment and the signal at 1h 10m was a little before the stabilization of the shape. The signal at 17h 10m was emitted in the dry state and the signal marked as wet was emitted in the wet state. The signal at the wet state was almost identical to the signals emitted from 2h to 7h after detachment. The measurements performed with other samples picked from different locations of the same patch on the

same tree showed changes in shape for smaller durations. Probably, the samples at different locations had different metabolic activities.

The final example demonstrates characterization of inherent structure in fluctuations. Fluctuations are quantified by its probability distribution that is the set of observed probabilities of detecting various numbers of photons. The probability distribution like Q value is another characteristic of a biophoton signal. The probability distribution of a biophoton signal is different from the probability distribution of a same strength photon signal of a non-living source. The probability distributions of different biophoton signals also differ. The observed probabilities in the spontaneous biophoton signal emitted by the above mentioned sample of *Xanthoria.parietina* at bin sizes equal to 100ms, 200ms, 300ms, 400ms and 500ms are depicted with different symbols in Fig.5. The measurements were made after five days of detachment. The sample was kept in the dark for 4h before measurements. The measurements were made with increasing bin size one after the other and there were 20,000 contiguous measurements at each bin size. It took 8h 20m to complete these measurements. The Q value of measurements at different bin sizes varied from 0.80 to 1.43 indicating that distributions are super Poisson and inherent structure are slightly different. The quantum model mentioned above characterizes distributions at all bin sizes of a stable biophoton signal by four parameters- one parameter is fixed by the average number of detected photons and the three parameters are common to all distributions. The common parameters in the notation of Ref [8-9] are r, $\theta$ and $\Phi$. The parameters specify a quantum squeezed state assumed to be the state of biophoton signal. The common parameters were determined from the observed probabilities by least square minimization. The common parameters and calculated probabilities are also depicted in Fig.5. The calculated probabilities are close to the observed probabilities and are shown by lines joining them. The agreement between calculated and observed probabilities further the condition of commonality is slightly relaxed. We have measured fluctuations for 24h in a sample of *Parmelia.tinctorum* [9] using various bin sizes and found that probability distributions are characterized by only three parameters. We have also measured the probability distributions of 21 different spectral decompositions of the signal emitted a sample of *Parmelina.wallichiana* obtained by inserting long pass and interference filters and found that probability distributions of spectral decompositions are describable by the same squeezed state parameters. We, therefore, consider these parameters as new characteristics of a sample, which are measurable in about 25m with bin size of 100ms. The utility of the new characteristics is being explored.

The above examples were chosen to demonstrate the potentiality of a quick, sensitive and non invasive technique that has only nominal running cost. The technique exploits the uniqueness of a biophoton signal by identifying and characterizing its patterns. The origin of photon emission and patterns are not known. There are only speculations. Our speculation is that the patterns originate from the coherence of live objects. Coherence means that some constituents of a live object act in a coordinated and cooperative manner. The cooperative functioning is a hallmark of living system and is manifested in various levels. It is manifested in the coordination among different reactions visualized in a biochemical pathway. The mechanism of cooperative functioning may emit or absorb photons to balance energy. Photons emitted in the mechanism contain information about cooperative acts and of the mechanism of cooperation in some properties of the signal. The patterns observed in biophoton signal could be the properties loaded with this information. We have to discover how to decipher the information. The success of quantum model in identifying these patterns is an intriguing aspect with profound implications. A photon signal of pure quantum nature has to emanate from quantum structures inherent in live objects. The quantum structures could be some complexes of biomolecules. But the important thing is that biophoton signals can be put to many uses even without the knowledge of their origin.

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**Figure captions:**

**Fig.1: Universal shape of a biophoton signal:** A typical signal is drawn that high lights important feature of biophoton signals.

**Fig.2: Light induced biophoton signal of *Parmelina.wallichiana***: The sample was stimulated by 5s exposure to white light after placing it in the dark measuring chamber for an hour. The emitted photon flux was measured in the range (1ms-11111s) with different bin sizes indicated in the figure. The curve is a fit to the data by Eq.(1) with the parameters depicted in the figure.

**Fig.3: Effect of temperature on spontaneous biophoton emission in lentil seedlings:** Spontaneous biophoton emission from lentil seedlings at $22^0$C, $37^0$C and $45^0$C. The figure also gives Q value of the observed signal at three temperatures.

**Fig.4: Changes in the light induced biophoton signal of a fresh sample:** The **c**hanges occurring in the signal of a sample of *Xanthoria.Parietina* after its detachment along with its substrate from the host are depicted from 50 to 100s after exposure to light at four representative situations. The line graph gives the signal of the sample made wet after its water evaporation at room temperature.

**Fig.5: Probabilities of detected photons at five bin sizes:** The symbol give the observed probabilities determined from 20,000 measurements in contiguous bins at each bin size in the spontaneous biophoton signal emitted by a sample of *Xanthoria.Parietina*. The measurements were made in increasing bin size after placing the sample in the dark measuring chamber for 4h. The duration of measurements was 8h20m. These probabilities determined three parameters of an assumed squeezed state in the quantum model given in the figure. The lines give the calculated probabilities in the quantum model.

**Fig1**

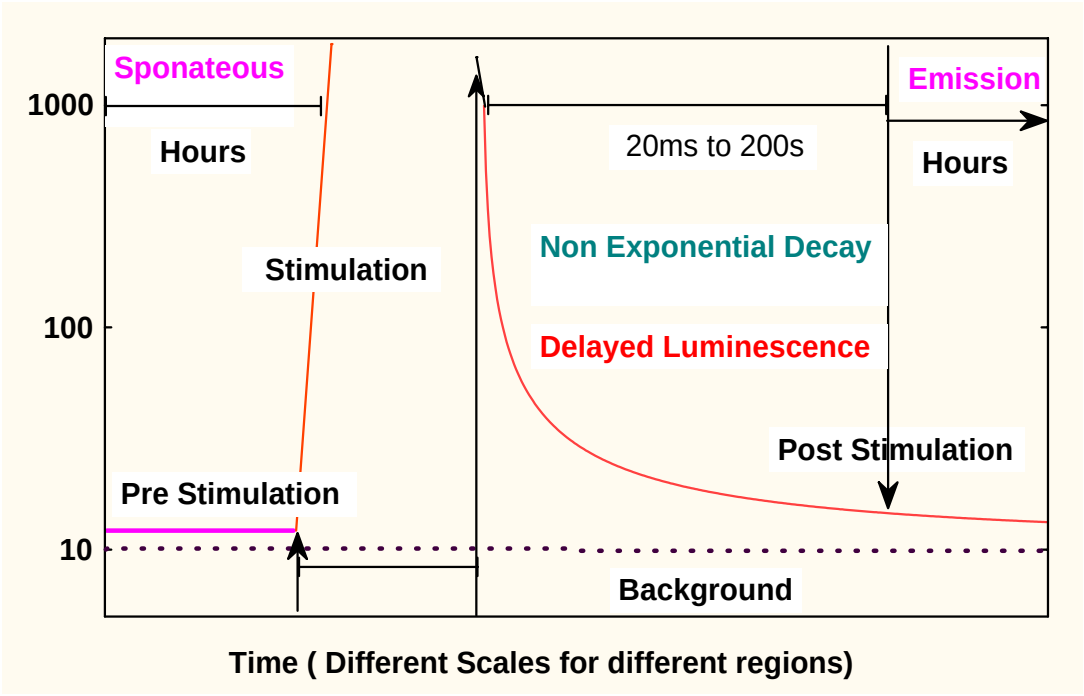


**Fig2**

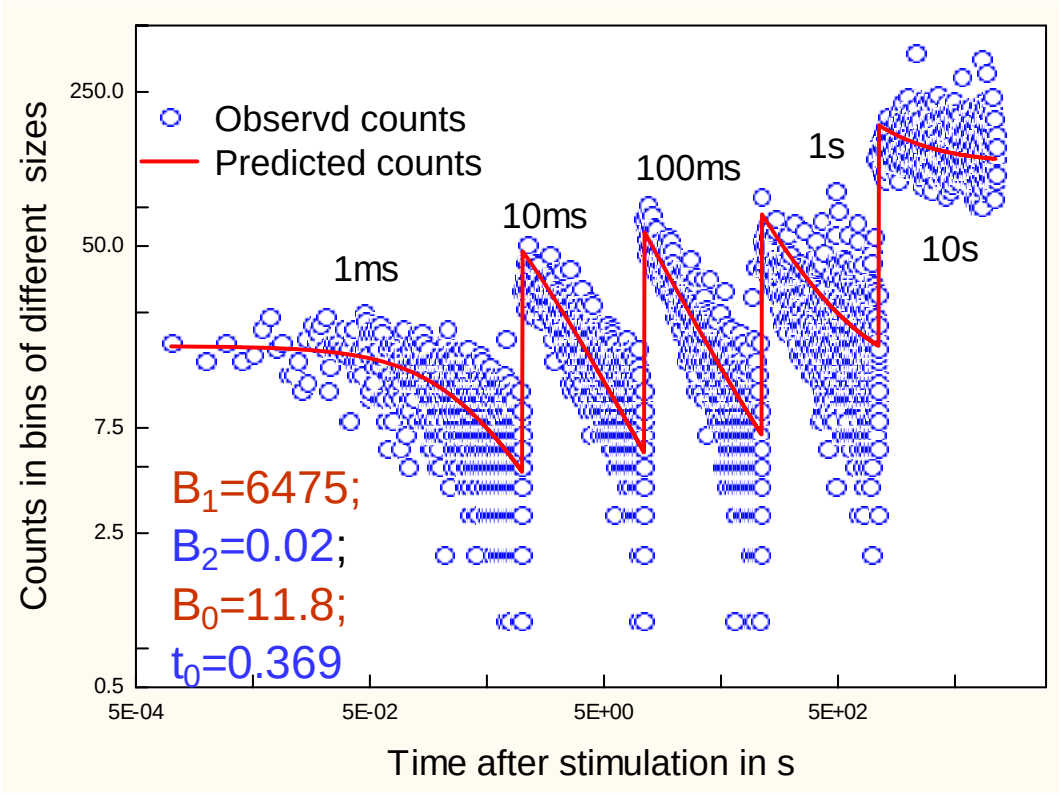

Observd counts
Predicted counts
1ms
10ms
100ms
1s
10s
B1=6475;
B2=0.02;
B0=11.8;
t0=0.369
Counts in bins of different sizes
Time after stimulation in s
250.0
50.0
7.5
2.5
0.5
5E-04
5E-02
5E+00
5E+02

**Fig. 3**

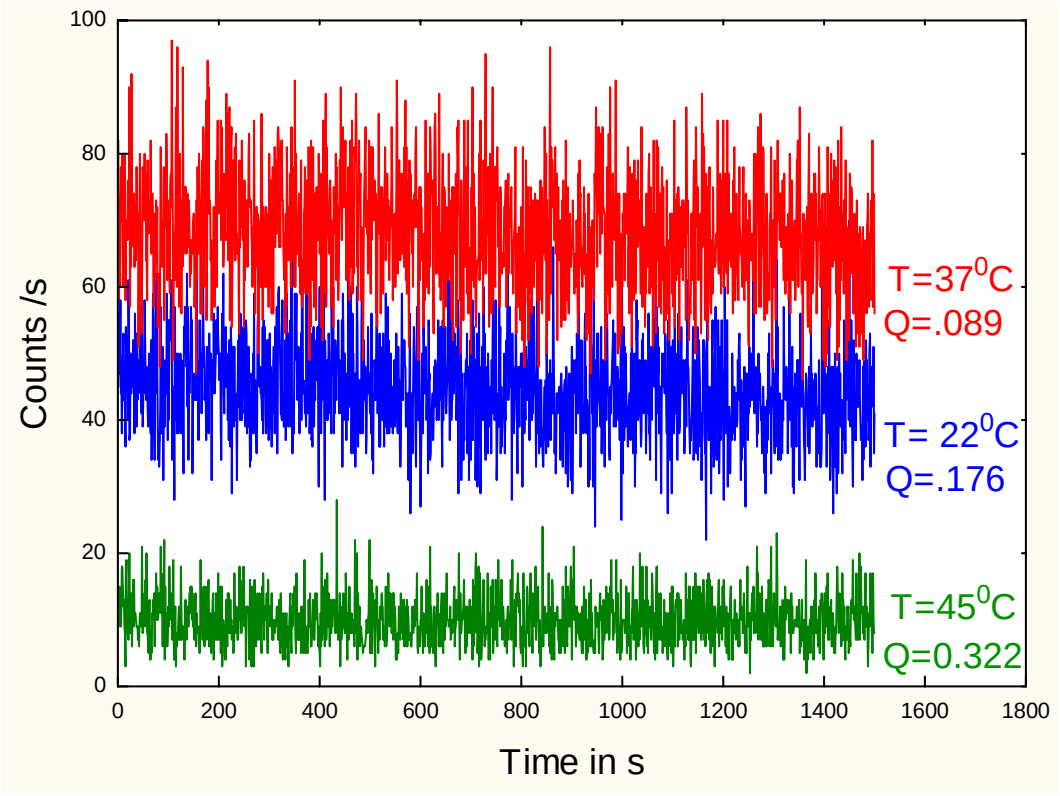

T=37⁰C
Q=.089
T= 22⁰C
Q=.176
T=45⁰C
Q=0.322
Counts /s
Time in s
100
80
60
40
20
0
0
200
400
600
800
1000
1200
1400
1600
1800

**Fig4**

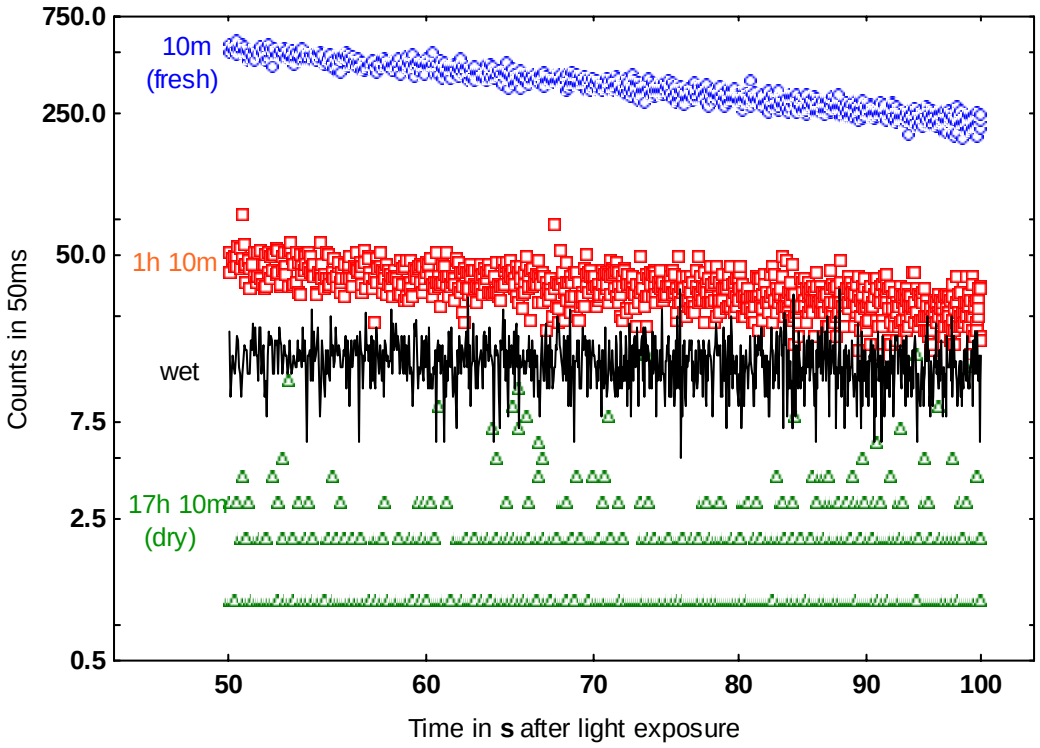
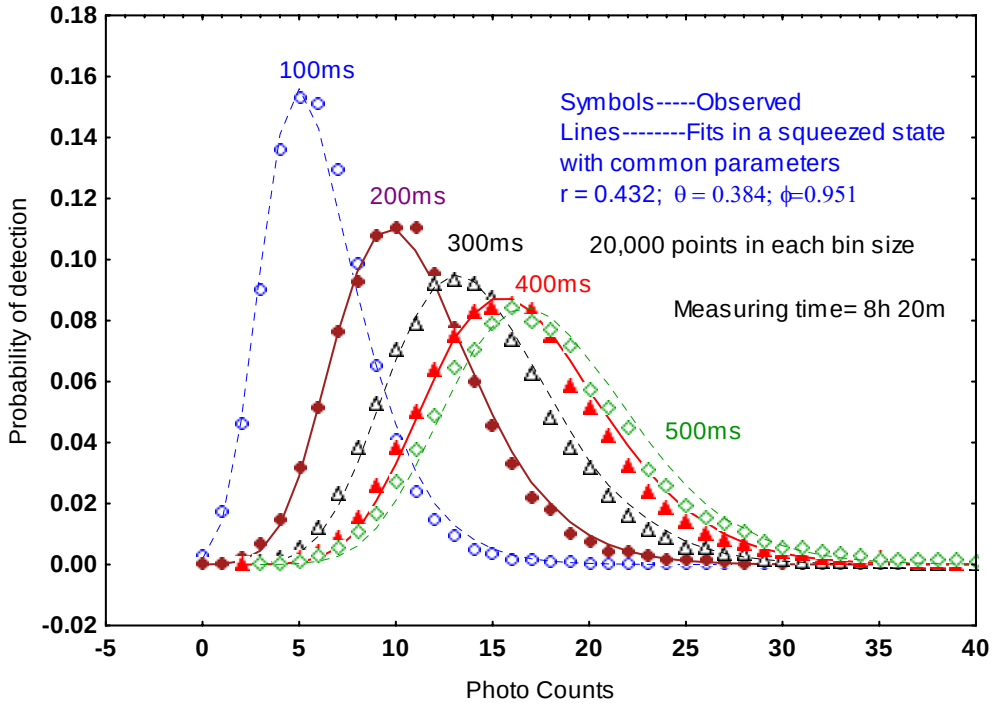

750.0
250.0
50.0
7.5
2.5
0.5
Counts in 50ms
10m
(fresh)
1h 10m
wet
17h 10m
(dry)
50
60
70
80
90
100
Time in s after light exposure

**Fig 5**


0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
-0.02
Probability of detection
100ms
200ms
300ms
400ms
500ms
Symbols-----Observed
Lines--------Fits in a squeezed state
with common parameters
r = 0.432; θ = 0.384; ϕ=0.951
20,000 points in each bin size
Measuring time= 8h 20m
-5
0
5
10
15
20
25
30
35
40
Photo Counts

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