Ultraweak Biophotons: general aspects and new experimental data

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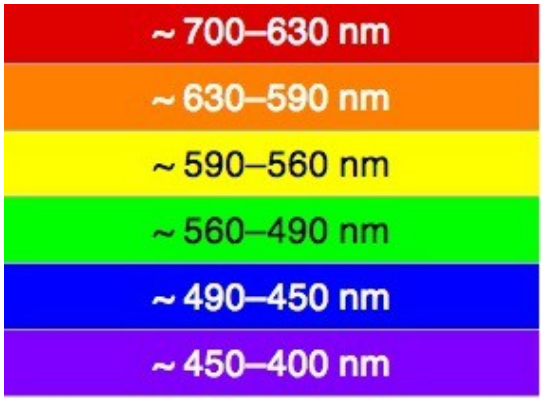
Biophotons : an ultra-weak e.m. emission of living organism (from few to some hundred photons/sec/cm^2) within the visible spectral region (200 to 800 nm).
When you kill the organism, this emission ends



Visible spectral region – photon energy from about 1.7 to 3 eV

A bit of history

In the early 1920s a russian biologist A.G. **Gurwitsch** proposes the presence of an electromagnetic emission to explain some experiments on the germination and development of plants. The results obtained confirmed his hypothesis of a weak radiation from cells, which is able to trigger the growth of other cells

In 1954 L. **Colli** and U. **Facchini** (Milan Politecnico) published a paper intitled "Light Emission by Germinating Plants"

In the early 1980s, **Popp** started working on the subject and his works had a good global resonance.
In Italy the group of F. **Musumeci** (Catania) worked on this topic since the early 1990s - They used a light stimulated emission

A.G. Gurwitsch, Arc. Entw. Mech. Org. **100**, 11 (1923)
L. Colli and U. Facchini, Il Nuovo Cimento **12**, 150 (1954)

Colli and Facchini experimental set-up

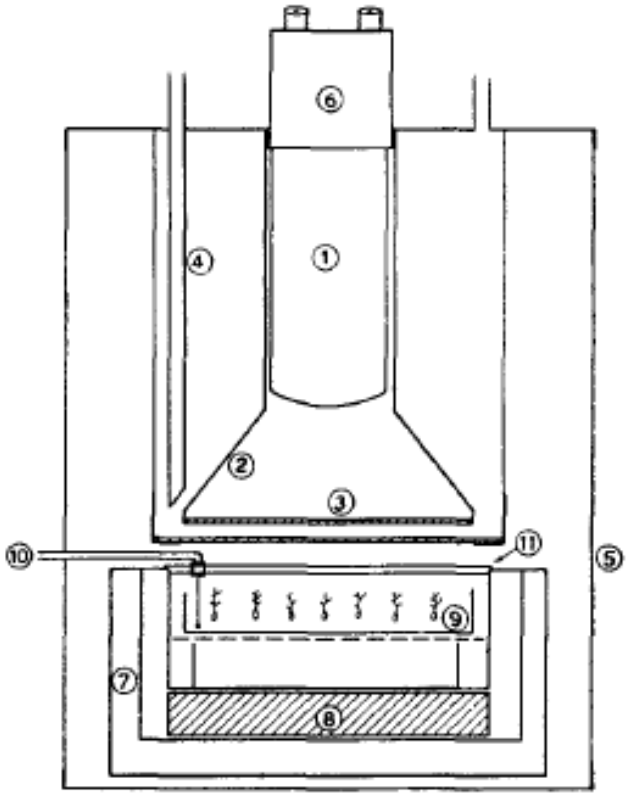


Fig 1. – Scheme of the photomultiplier-thermostate setting. A similar setting is used, cooled with dry ice. 1) Photomultiplier, 2) diffusing light guide, whitened with magnesium oxide, 3) glass, 4) water cooler, 5) light tight box, 6) socket containing the voltage divider, 7) thermostate box, 8) electric heating element, 9) glass plate containing the plants under study, 10) thermocouple thermometer 11) lucite lid.

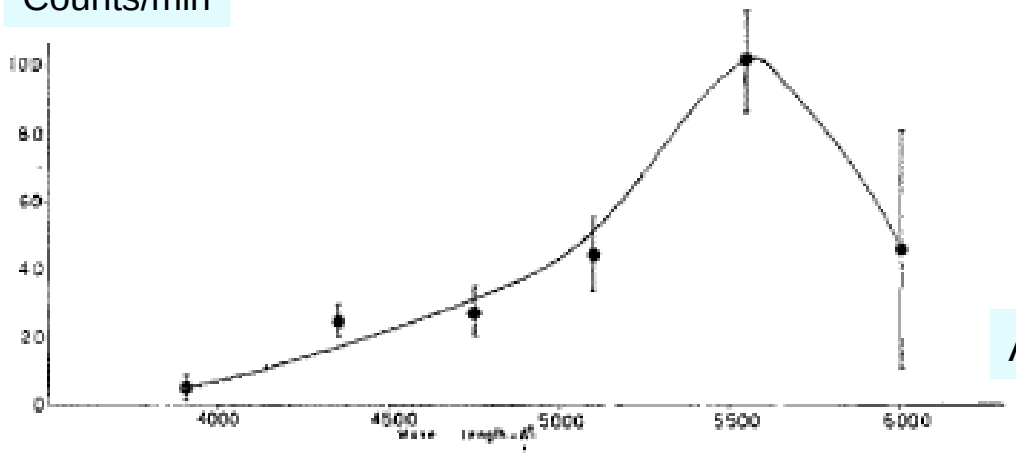
300 hundred plants in a plate of about 14 cm of diameter – The plants were grown in the dark to avoid any phosphorescence residues.

TABLE I. – *Results on seedlings.*

Phototube	Kind of the plant used (6 days old)	Fresh weight	Temperature	Total pulses/min	Background pulses/min	Effect pulses/min
N. 143, cooled with H_2O	wheat	60 g	30° C	7 936	4 608	3 328
N. 195, cooled with dry ice	lentils	60 g	22° C	7 680	1 024	6 556
» »	corn	60 g	22 °C	11 520	1 280	10 240
» »	corn (grown in aseptic conditions)	60 g	22 °C	8 960	1 280	7 680

They found that germinating seeds and plants have a weak electromagnetic emission of the order of 100 photon/min/cm² in the visible energy range. Such emission has a slight frequency dependence and is influenced by the type of treatment done on the seeds or plants

Counts/min



Angstrom

Fig. 4.—Luminescence spectrum: the points represent in arbitrary scale the average values obtained in various conditions, and with various kinds of seedlings.

Counts/min

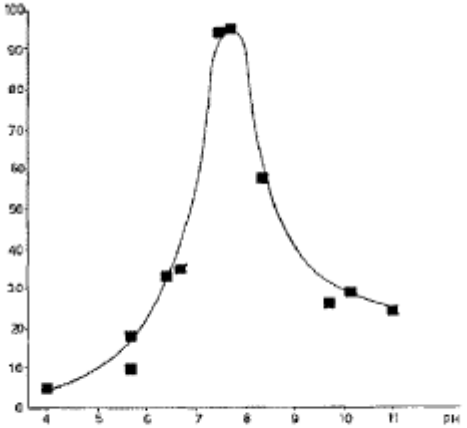


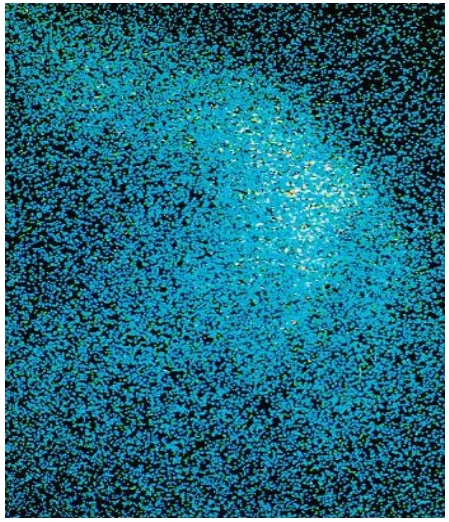
Fig. 3.—Luminescence intensity of extracts of lentil seads versus pH values.

L.Colli, U. Facchini et al. Experientia **11-12**, 479 (1955)

more recently

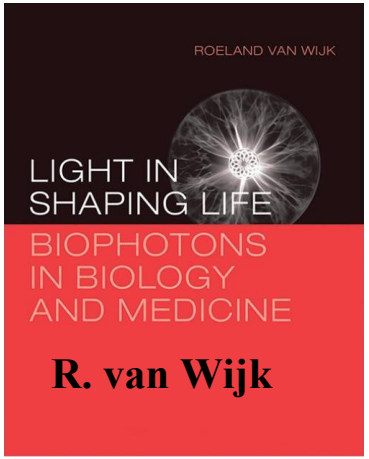
In Japan prof. H. Inaba started in 1986 a 5 years ERATO project called INABA Biophotons Project https://www.jst.go.jp/erato/en/research_area/completed/isf_P.html

This project focused on the ultra-weak (tens of photons per second) light that is emitted from, transmitted in, and absorbed by biological tissue and cells. These "biophotons" are quite different from known relatively intense bioluminescence emissions which are detectable by the human eye and for which specific substances are known to be responsible. The difference is in the fact that these biophotons originate completely from chemical activity within cells, and not as a response to external light, or other, stimulation.



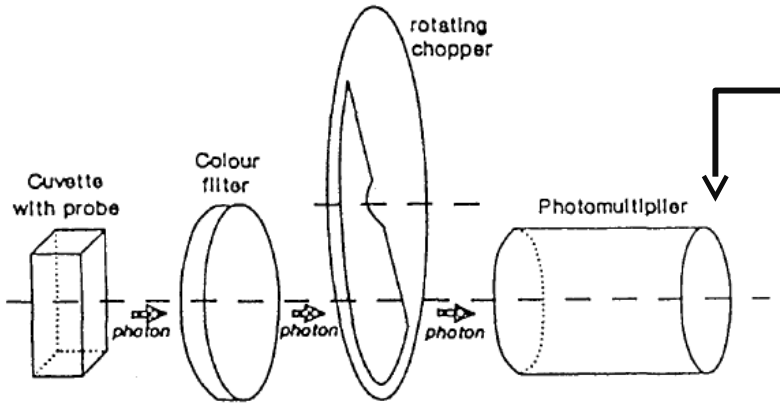
·An image of the ultraweak photon emission penomenon accompanying soybean germination obtained for the first time by the Inaba Biophoton team. The photo shows light emission concentrated around the hypocatyl when the germ is growing and cells are actively dividing

more recently



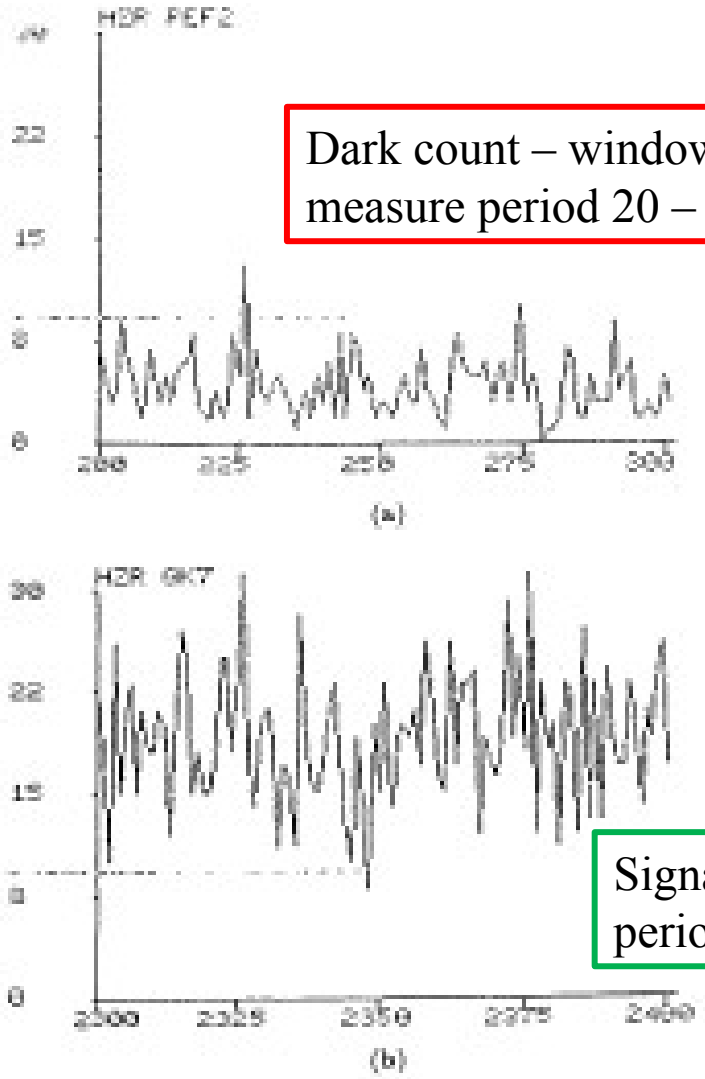
The F.A. Popp work

Diameter of 44 mm



Photomultiplier in the range 200 – 800 nm
(in reality it has an efficency of 30% at 250 nm that goes down at 500 nm to arrive at almost 0 at 850 nm)

F.A. Popp et al . Modern Physics Letter B, Nos **21&22**, 1269 (1994)

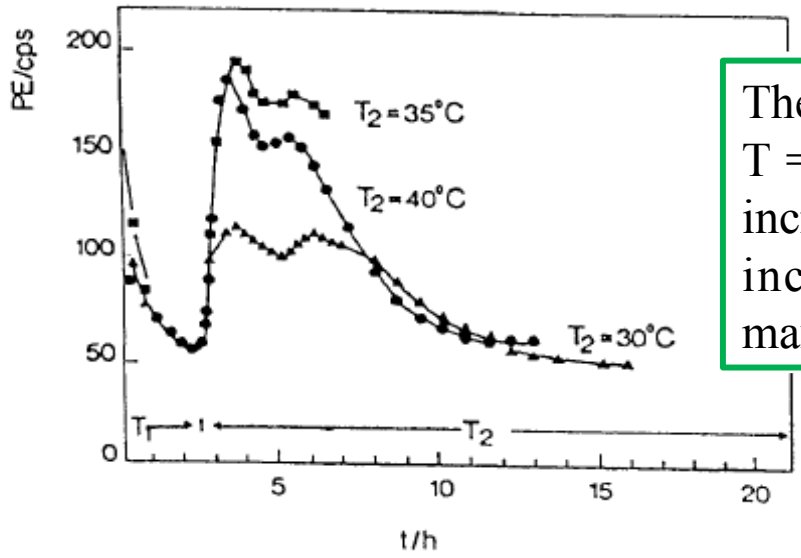


Dark count – window of 0.1 sec – measure period 20 – 30 sec.

Signal with cucumber plants - measure period 230 – 240 sec.

Fig. 2. (a) Dark count rate of the measuring chamber (in counts per 0.1 s) during time (from 20 to 30 s). (b) Count rate (including dark count rate) of cucumber seedlings (counts per 0.1 s) during time from 230 to 240 s in a quasistationary state.

Photomultiplier works at low temperature (-30°) to decrease the dark count



The cucumber seedlings after being kept at T = 19 ° for a few hours the temperature is increased up to T2 in one hour - there is an increase in emission that reaches a maximum and then a slow decrease

Reaction to a toxic agent - these types of reactions are not unique - sometimes small concentrations of toxic agent cause large variations and vice versa.

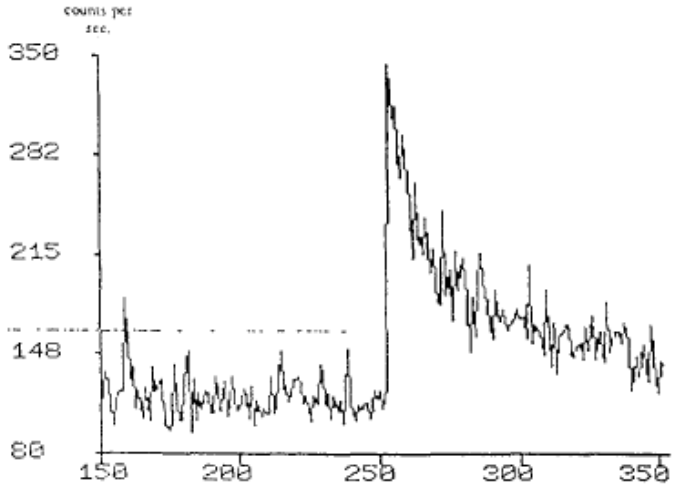
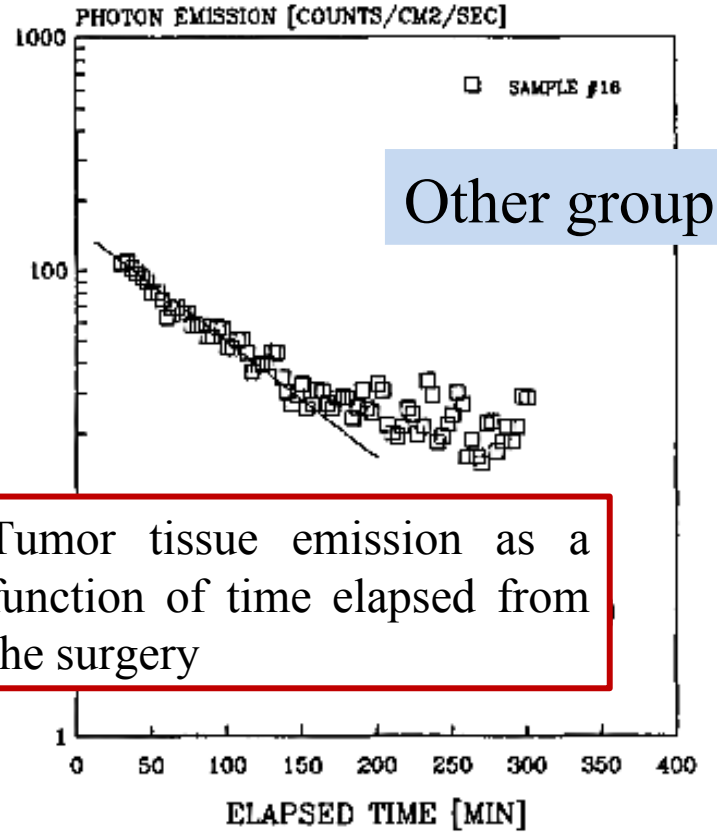


Fig. 8. After the addition of a highly diluted toxic agent (Staphisagria D5 1:10^5 in physiological saline) at 250 sec, the biophoton intensity of cucumber seedlings (in counts per second) increases considerably indicating an effect of the toxic chemical. One hundred seconds after administration of the toxic agent, the photon intensity dropped down to almost the original order of magnitude.

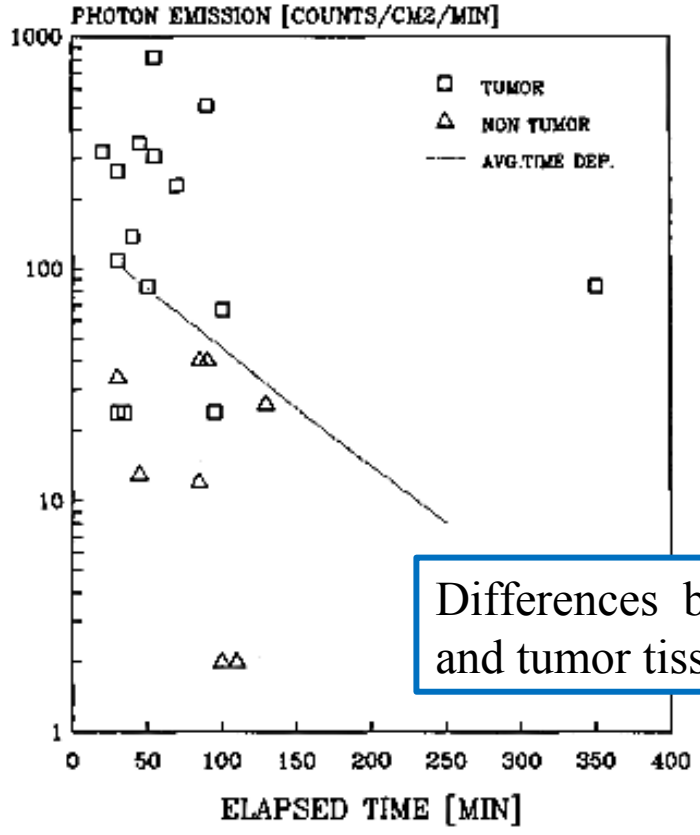
some points from Popp

- The spectral distribuition $n(\lambda)$ does not display small peak around definite frequencies. It is quite flat at least in the visible range
- The photoncount statistic which account for the probability $p(n,\Delta t)$ of registering n photon in the time interval Δt seems to follow a Poisson-like distribution
- Reaction to stress are frequently indicated by an increase in biophoton emission



Other groups

Tumor tissue emission as a function of time elapsed from the surgery



Differences between healthy and tumor tissues

Figure 2. *a* Intensity of light emitted by a tumor sample vs time elapsed from the surgical removal; *b* Intensity of light emitted by normal (△) and tumor (□) samples vs time elapsed from surgical removal (see text). The dashed line represents the average measured decay.

the tissue is stored at 37 ° in the dark and immersed in a solution that allows its metabolic activity.

Grasso et al. Experientia 48, 10 (1992)
(Musumeci group)

Change of the biophoton emission from human body during the day

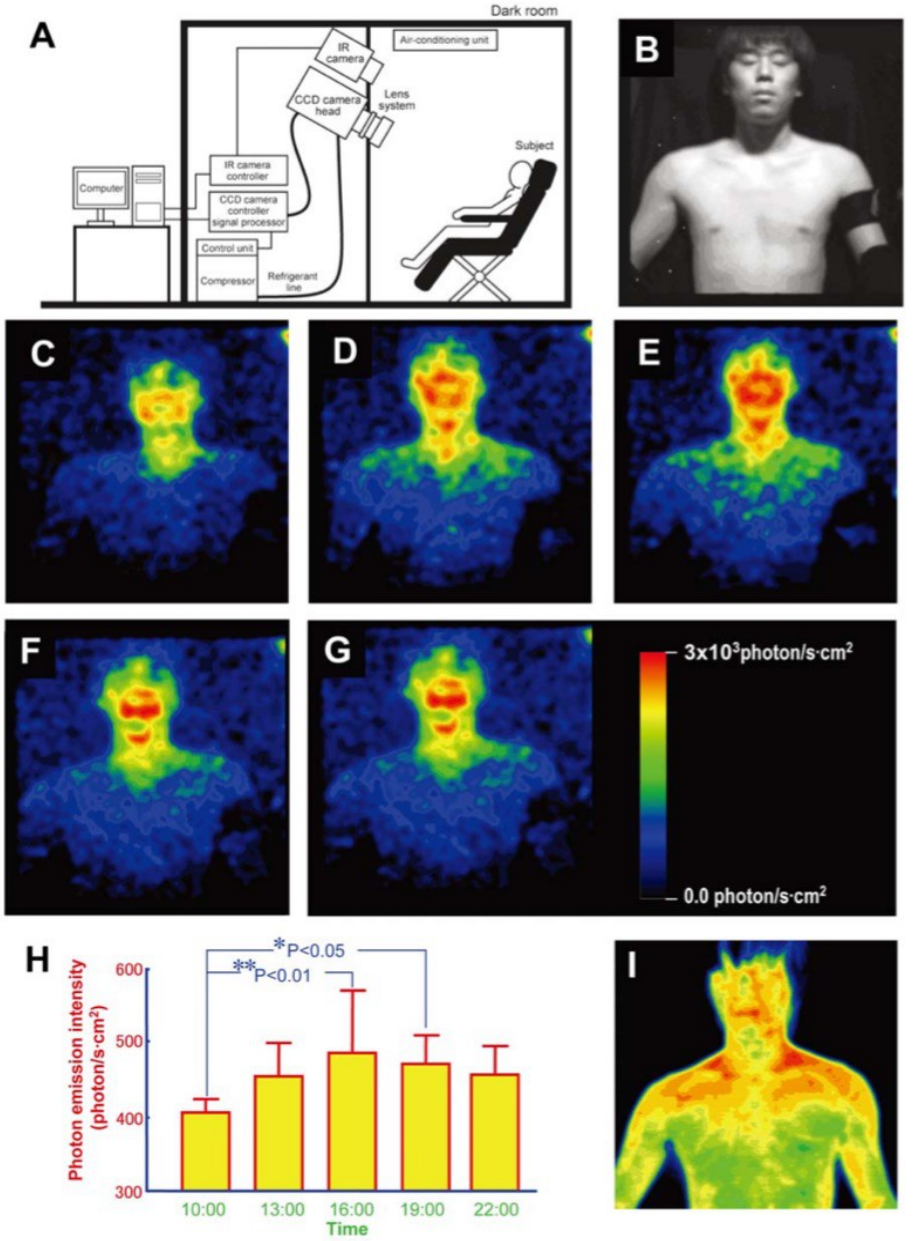


Figure 1. A. Schematic illustration of experimental setup. **B–F.** Images of ultraweak photon emission from human body. **B.** Image of the subject under light illumination. **C.** Image at 10:10. **D.** Image at 13:10. **E.** Image at 16:10. **F.** Image at 19:10. **G.** Image at 22:10 with a calibration bar which indicates the estimated radiation intensity expressed by photon number per unit of time per unit of skin surface. **H.** Daily rhythm of photon emission from face and body from 5 volunteers. Significant difference from the photon emission at 10:00 AM ($n=15$, Mean±SD; $^{**}P<0.01$, $^{*}P<0.05$). **I.** A typical thermographic image of the subject from **Fig. 1B–G**.
doi:10.1371/journal.pone.0006256.g001

Kobayashi M, Kikuchi D, Okamura H (2009) *Imaging of Ultraweak Spontaneous Photon Emission from Human Body Displaying Diurnal Rhythm.* PLoS ONE 4(7): e6256.

Human body

- Anatomic characterization
- Presence of deseases (i.e. left-right hand asymmetry associated to hemiparesys and cold)
- Age
- Physical activity
- Practice of meditation and effects of immagination
- Acupuncture points and meridians
- Effects of herbal products

Two possible models (up to now)

- Stochastic metabolic events excite cells that re-emit excess energy in the form of photons rather than in other dissipative processes. The source of such events can be oxidative processes and in particular the interaction with free radicals – Notice that we are dealing with an energy of 2-3 eV i.e. well beyond the thermal excitation energy.

- The alternative hypotesis assigns biphoton emission to a coherent EM field within and between cells from which biphotons are emitted by physiological processes. This emission could be used to exchange informations

Obviously the second hypothesis does not exclude the first one. Anyway this emission is strictly connected with the biochemical processes present in the living system.

Cellular Communication through Light

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Abstract

Information transfer is a fundamental of life. A few studies have reported that cells use photons (from an endogenous source) as information carriers. This study finds that cells can have an influence on other cells even when separated with a glass barrier, thereby disabling molecule diffusion through the cell-containing medium. As there is still very little known about the potential of photons for intercellular communication this study is designed to test for non-molecule-based triggering of two fundamental properties of life: cell division and energy uptake. The study was performed with a cellular organism, the ciliate *Paramecium caudatum*. Mutual exposure of cell populations occurred under conditions of darkness and separation with cuvettes (vials) allowing photon but not molecule transfer. The cell populations were separated either with glass allowing photon transmission from 340 nm to longer waves, or quartz being transmittable from 150 nm, i.e. from UV-light to longer waves. Even through glass, the cells affected cell division and energy uptake in neighboring cell populations. Depending on the cuvette material and the number of cells involved, these effects were positive or negative. Also, while paired populations with lower growth rates grew uncorrelated, growth of the better growing populations was correlated. As there were significant differences when separating the populations with glass or quartz, it is suggested that the cell populations use two (or more) frequencies for cellular information transfer, which influences at least energy uptake, cell division rate and growth correlation. Altogether the study strongly supports a cellular communication system, which is different from a molecule-receptor-based system and hints that photon-triggering is a fine tuning principle in cell chemistry.

Essentialy he repeated the experiment of Gurwitsch but with the protozoan Paramecium Caudatum. He followed mainly the population growth. It depends on the separating material (glass or quartz), and the number of cells.

He found that « ..**separated population of the ciliate P.C. interact with each other through glass under condition of complete darkness ..**»

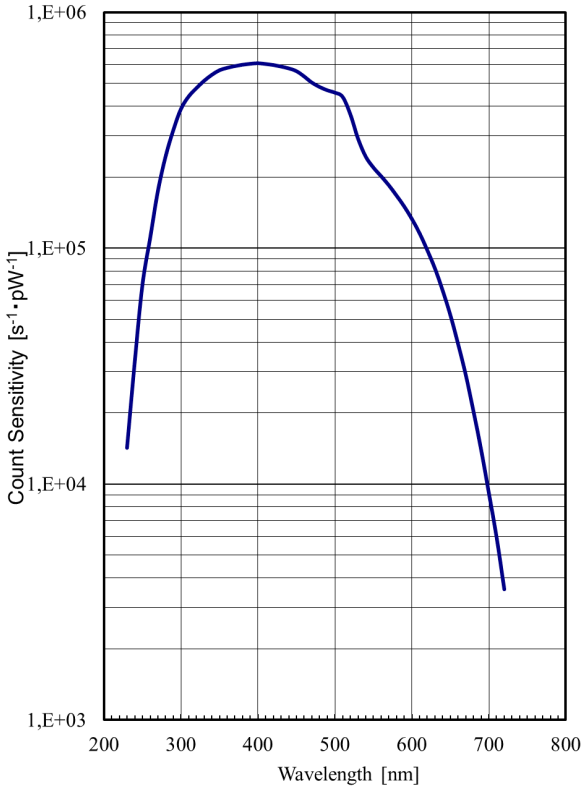
D. Fels , Plos One **4**, e5086 (2009)

Our experiment

The germination apparatus is formed by a black PVC germination chamber and a turnable wheel between the germination chamber and the detector

The detector

A Photon Counting Head: Hamamatsu H12386 110 (dark current ~1-2 photons/sec in the visible range)



- In our experiment the detector is placed on top of the germination chamber at a distance of 10 cm from the sample. The diameter of the sensible part is 0.8 cm (a solid angle of about 0.0016π)
- Between the germinating seeds and the detector is placed a turnable wheel holding few long pass glass color filters for energy discrimination.

Some details

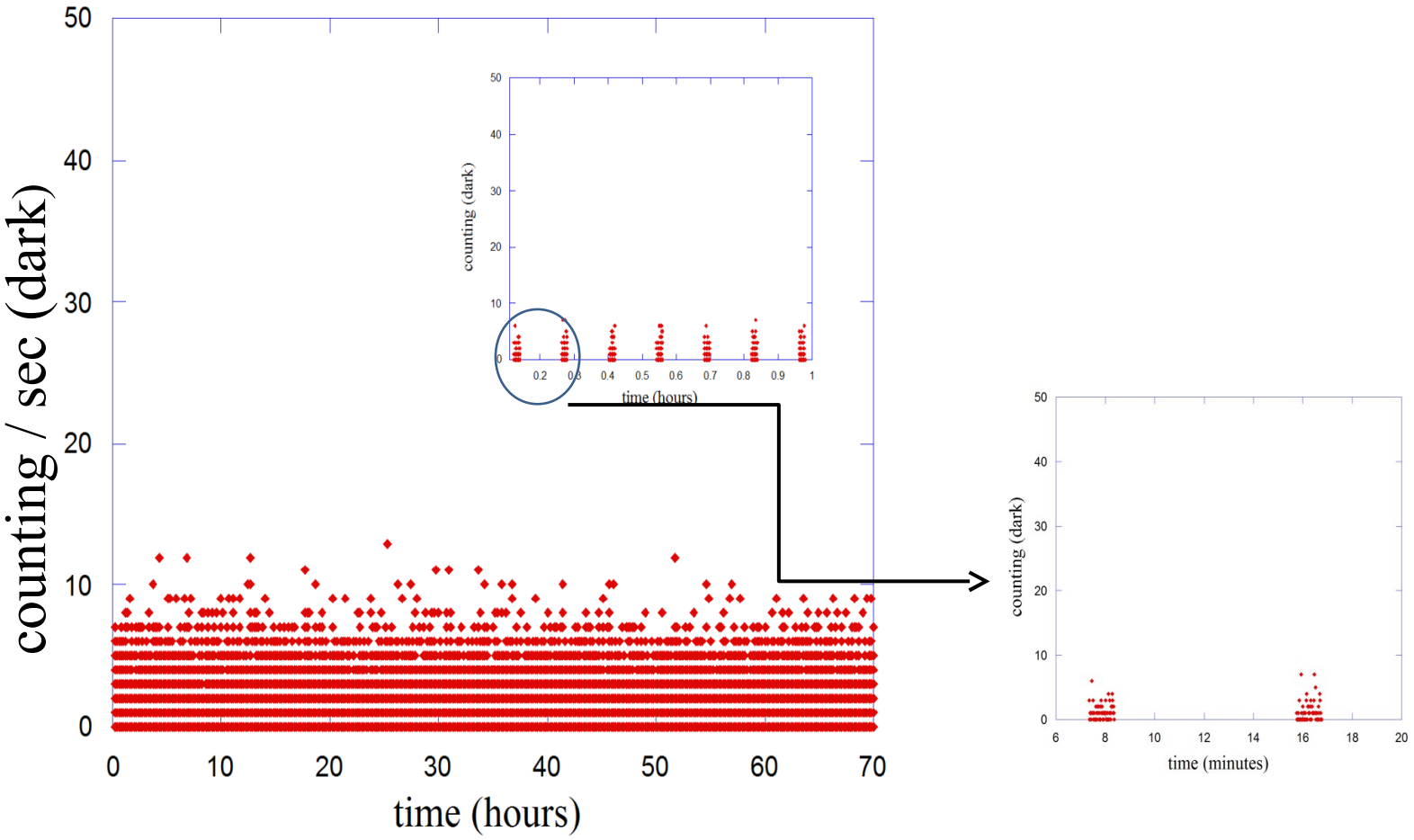
- All the experiment are driven by a LabView program that collects the emission data and drives the turnable filters wheel – 6 filters

- the time window Δt of acquisition is 1 sec – our counts are the number of photons within this time window.

- We collected data from a humid cotton bed without any seed. In this case we observed a monotonic decrement of photon emission which is the tail of the residual luminescence of the materials, consequence of the light exposure of the experimental chamber. The emission tail decreases in few hours down to about 3 photon/sec.

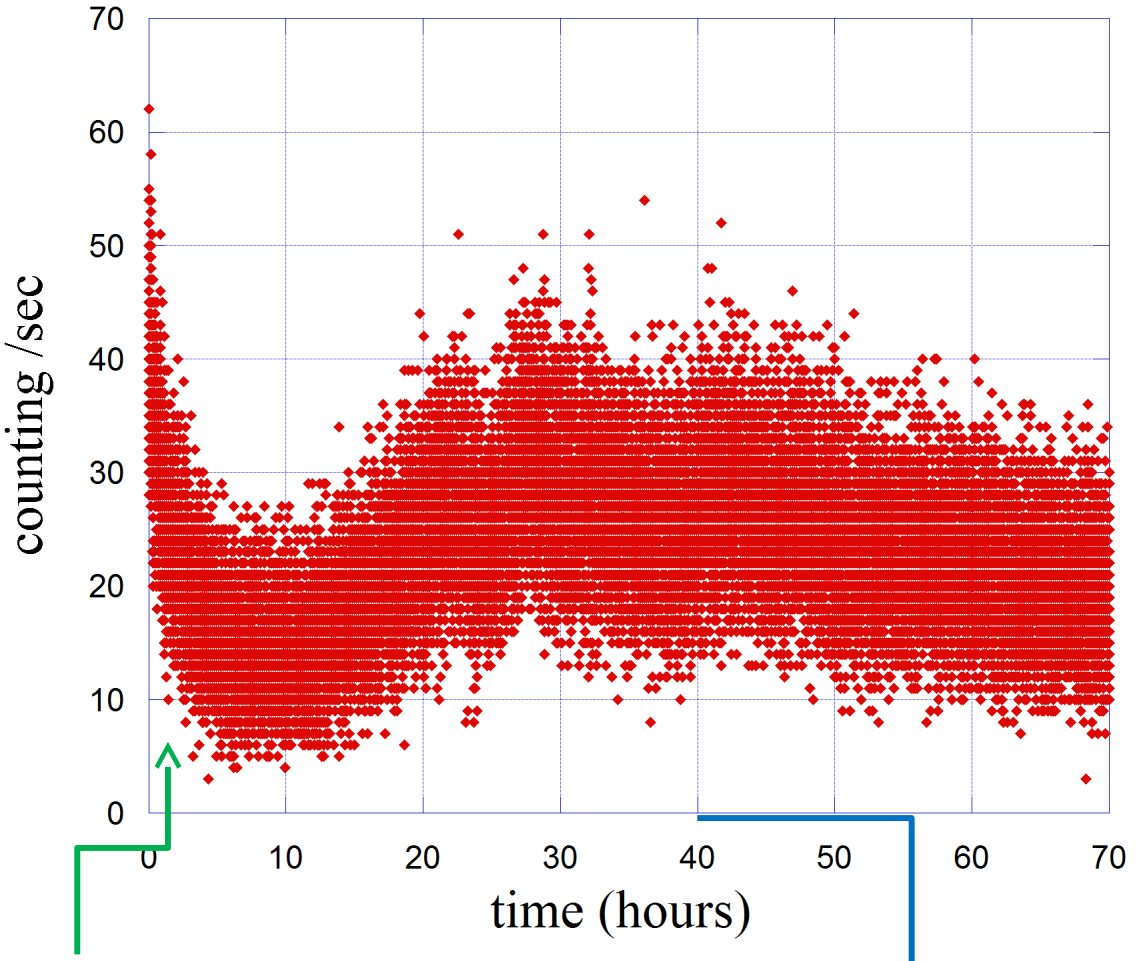
- When we performed experiments with “decorticated lentils” we observed that after a while (10 - 12 hours) the detected emission signals increase. Without germination we do not observe any emission, only the noise

Our dark – with a black cap



Because of the rotation of the wheel, the data have a bunch-type structure: the wheel stays in each position for 1 minute → there is a bunch every 443 seconds

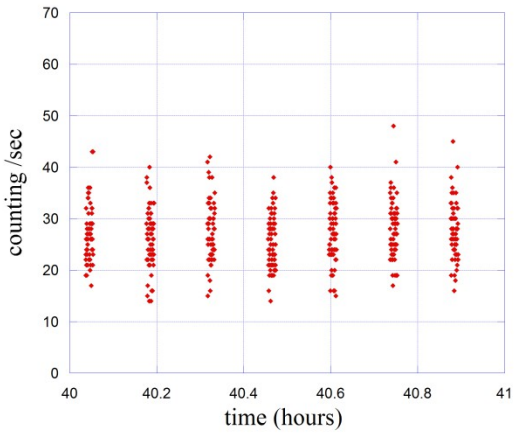
our experimental data with 76 seeds of lentil



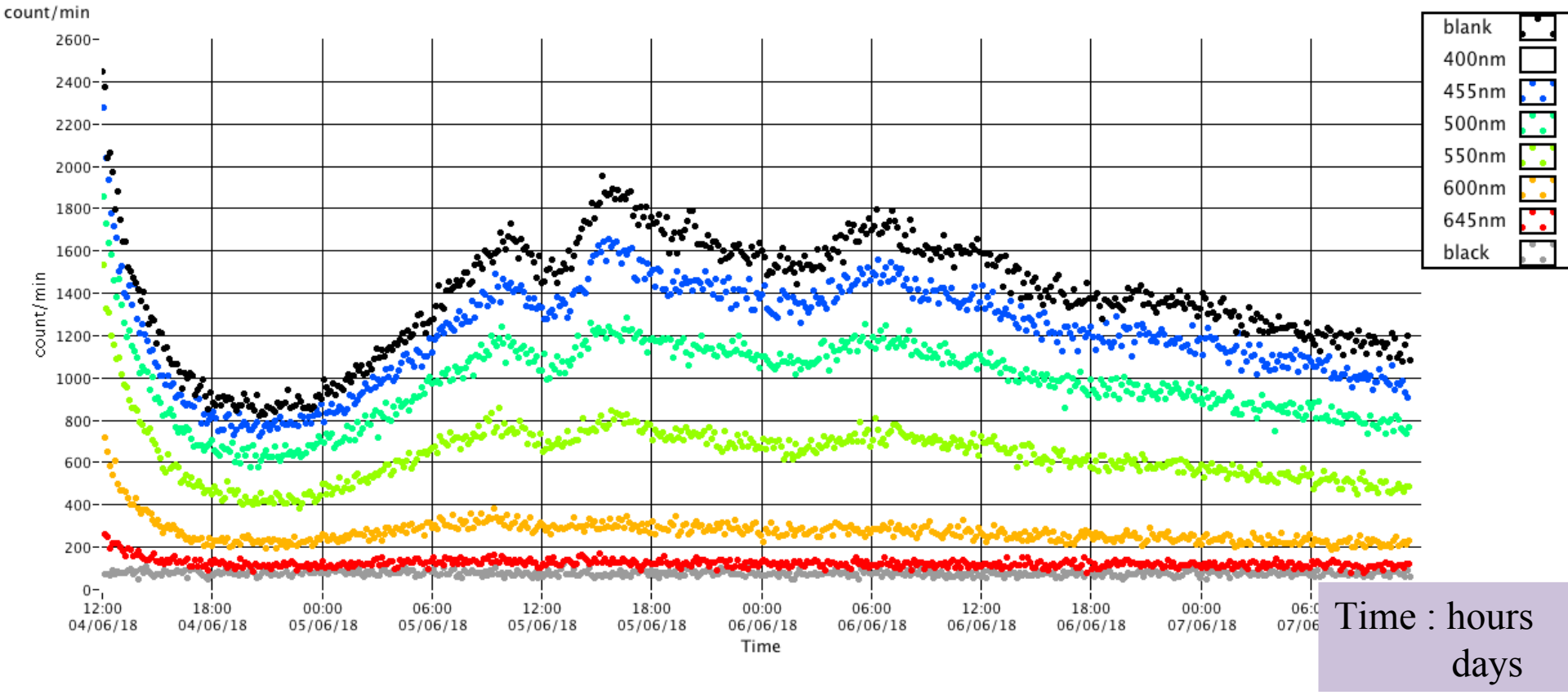
almost 3 days of measures

Again a bunch-type of structure – the exp. data without any filter. A signal to noise ratio larger than 10.

Residual luminescence – it goes away after about 12 hours

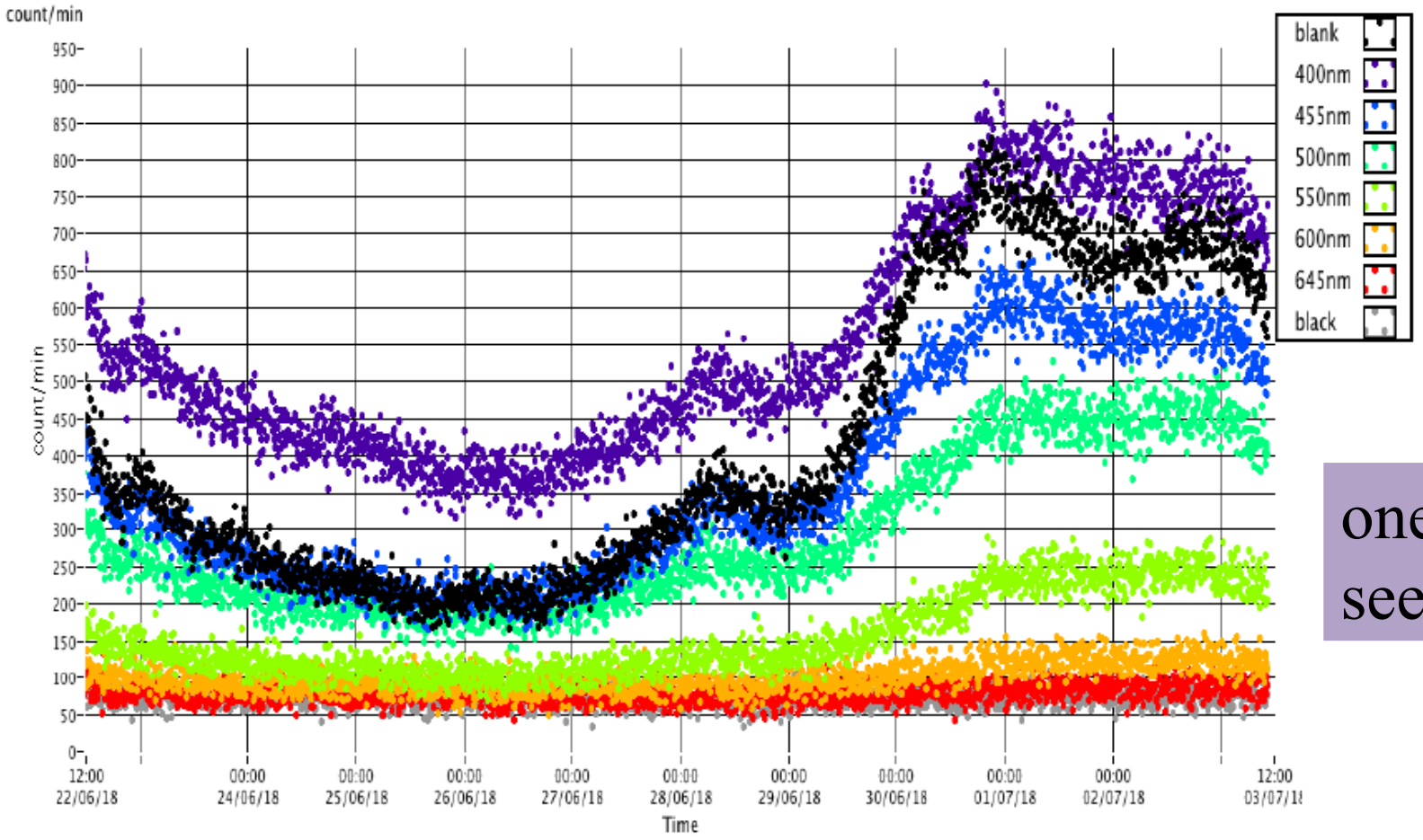


time dependance of the different spectral components – for clarity we report here the exp. data as counting/minutes



Time : hours
days

Different seeds have a different emission, but really similar.



one bean seed

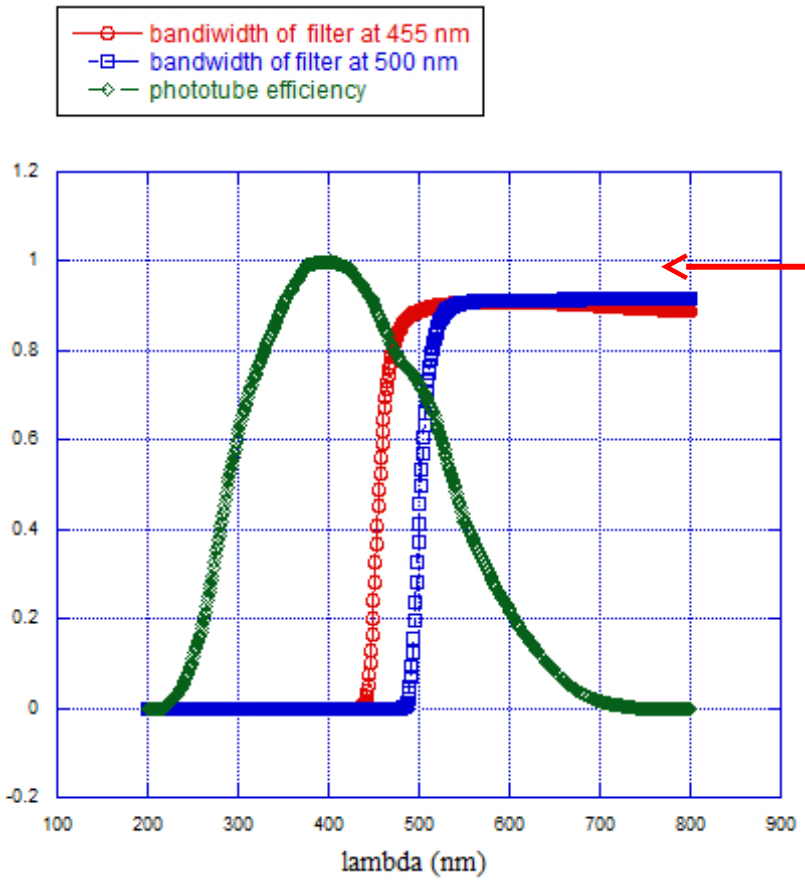
The shape is similar to the lentils case but with a completely different time evolution - time distance between the minimum and the first maximum is here about 2 days, while it is 12 hours in the lentils case.

Without filters we measure $N_{tot}(t) = \int_{\lambda_{min}}^{\lambda_{max}} n(\lambda, t)\alpha(\lambda)d\lambda$

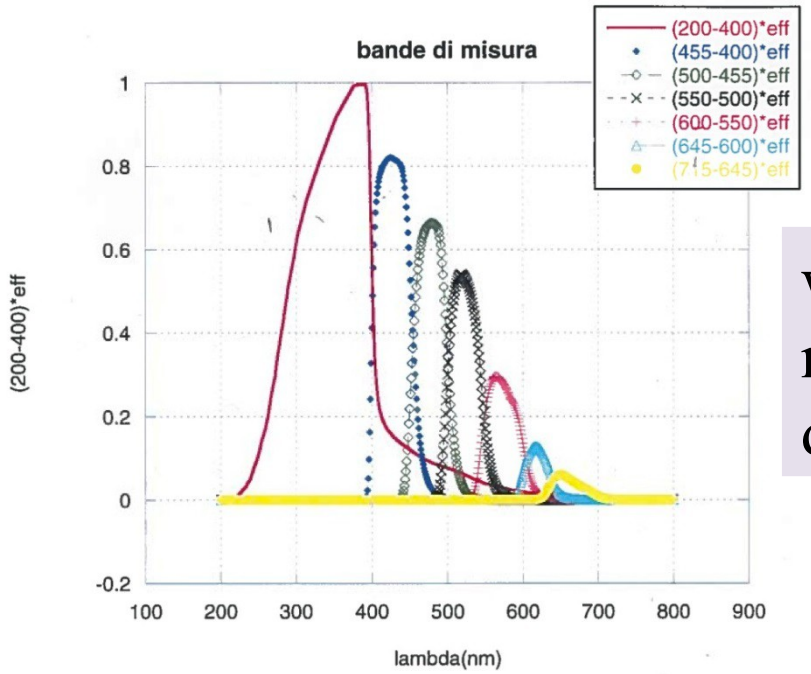
is the number of photon at time t and is the efficience of the phototube

$n(\lambda, t)$is the number of photon at time t and $\alpha(\lambda)$ is the efficience of the phototube

with filters $f_n(\lambda)$ we measure $N_n(t) = \int_{\lambda_{min}}^{\lambda_{max}} n(\lambda, t)\, f_n(\lambda)\alpha(\lambda)d\lambda$



we can calculate the difference between two adjacent filters

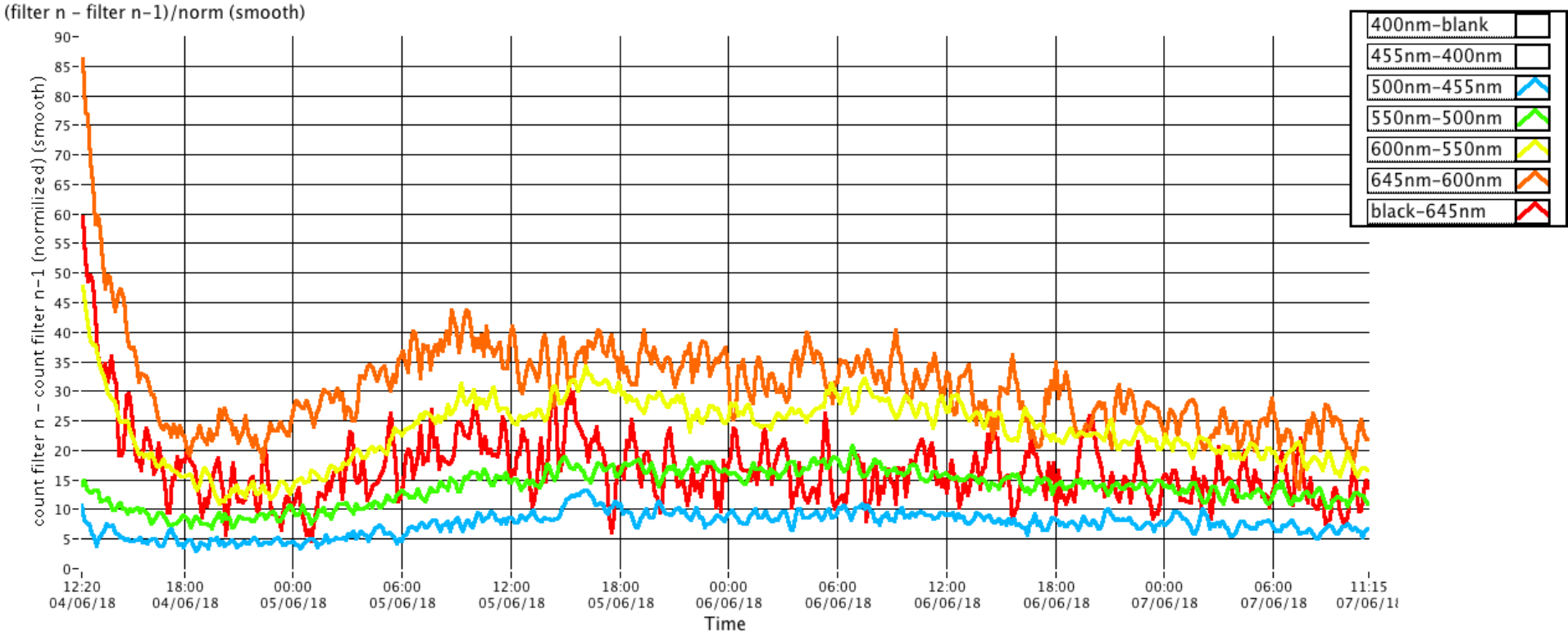


we can derive the average number of photons in the different bandwidths

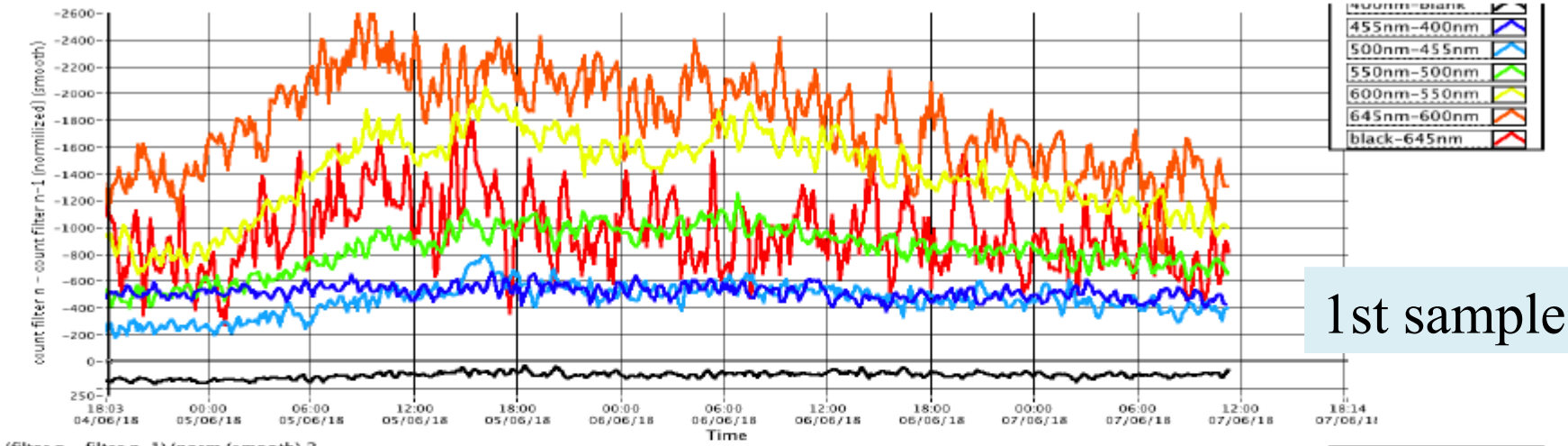
$$N_{m,n}(t) = N_m(t) - N_n(t) = \int_{\lambda_{min}}^{\lambda_{max}} n(\lambda,t)\alpha(\lambda)[f_m(\lambda) - f_n(\lambda)]d\lambda$$

$$N_{m,n}(t) \cong \bar{n}_{m,n}(t) \cdot \int_{\lambda_{min}}^{\lambda_{max}} \alpha(\lambda)[f_m(\lambda) - f_n(\lambda)]d\lambda = \bar{n}_{m,n}(t) \cdot I_{m,n}$$

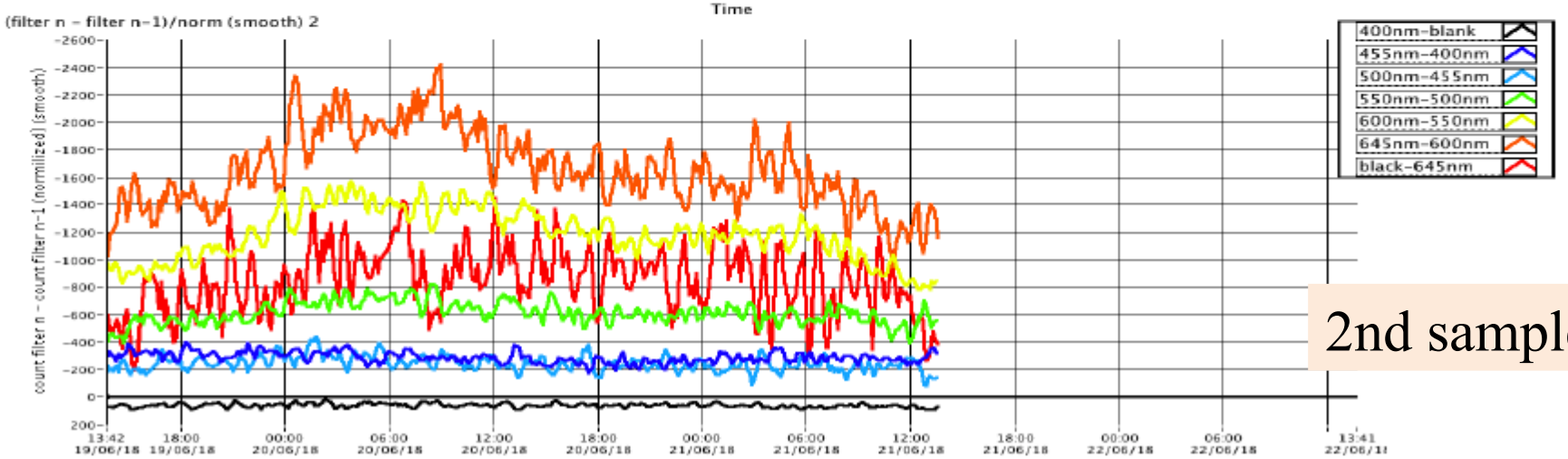
$$\bar{n}_{m,n}(t) = \frac{N_{m,n}(t)}{I_{m,n}}$$



Main emission in the spectral window 550-650 nm (about 2 eV)
The contribution of the different spectral components depends on time.



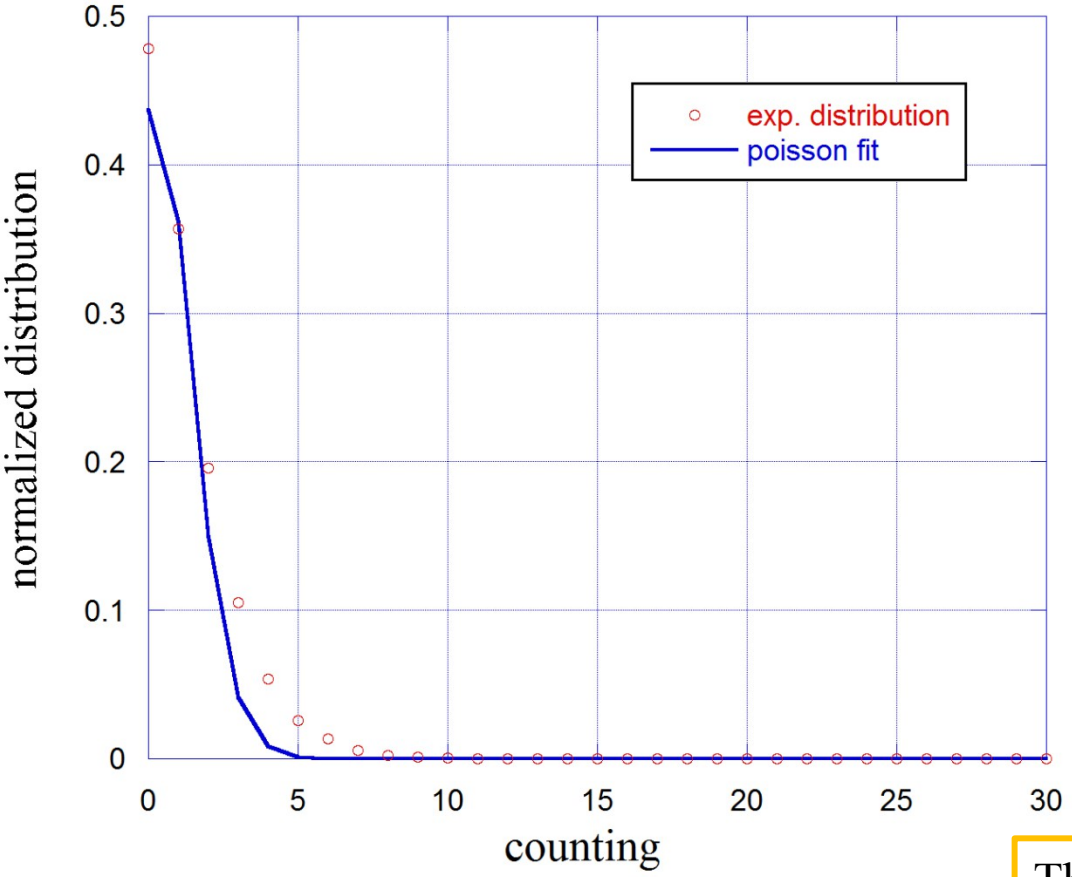
1st sample



2nd sample

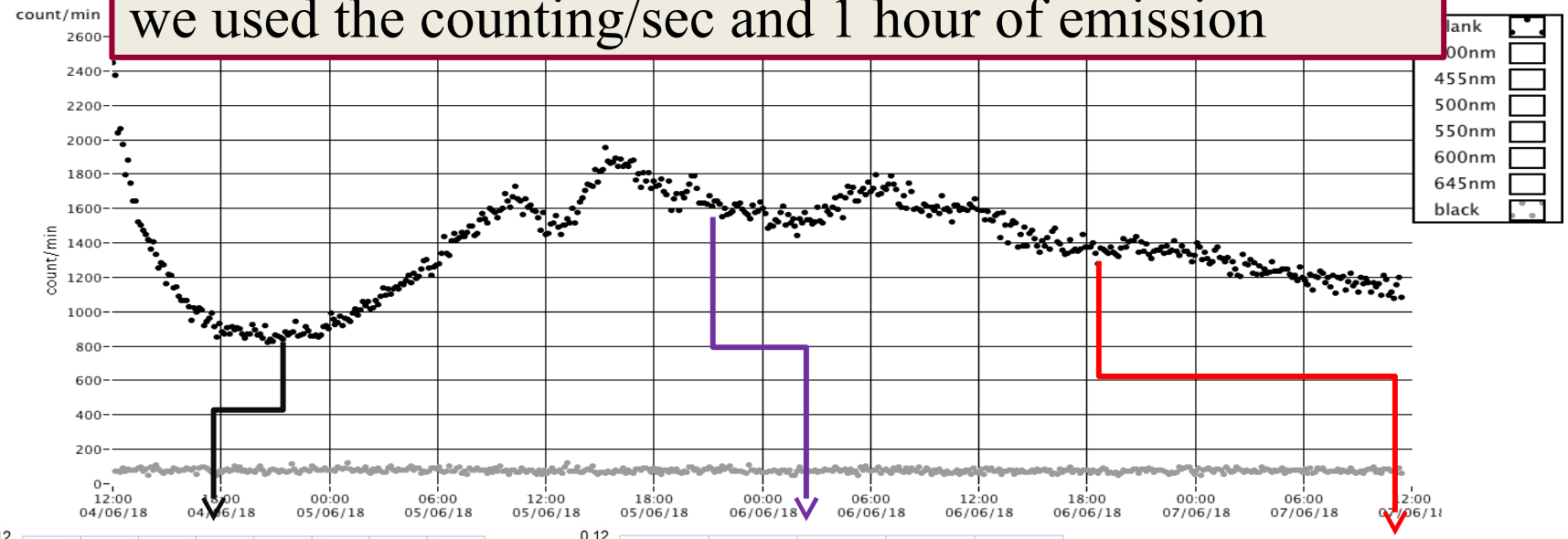
Two sets of data coming from the same number of lentil seeds: the bahaviour is not equal but has a similar shape

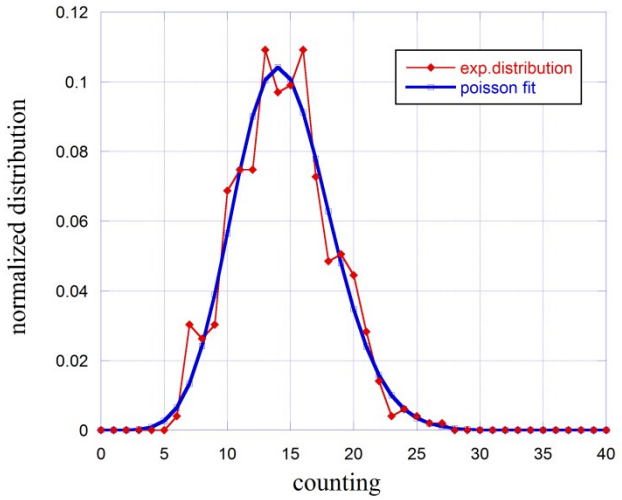
Dark count distribuition p(n,Δt) – Δt =1 sec



The fit with a Poisson distribution gives an average value of 0.827±0.03 count/sec – the experimental average is <n>=1.566

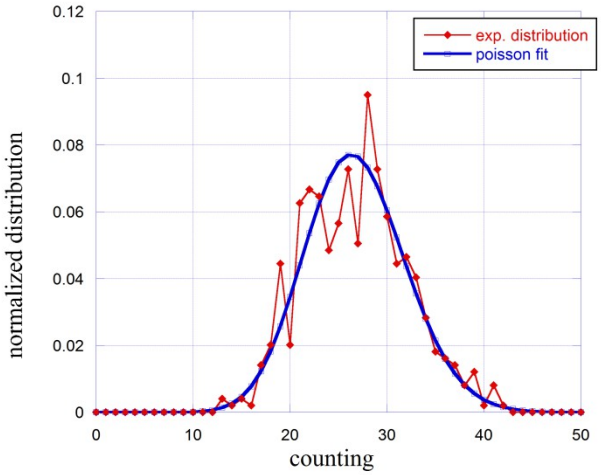
Time evolution of the p(n,Δt) of the total emission – we used the counting/sec and 1 hour of emission





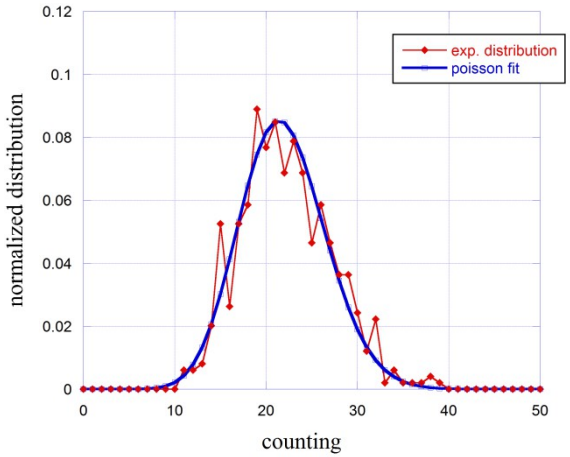
<n>=14.51±0.10

<n_{exp}>=14.40; σ^2_{exp}=14.60



<n>=26.80±0.21

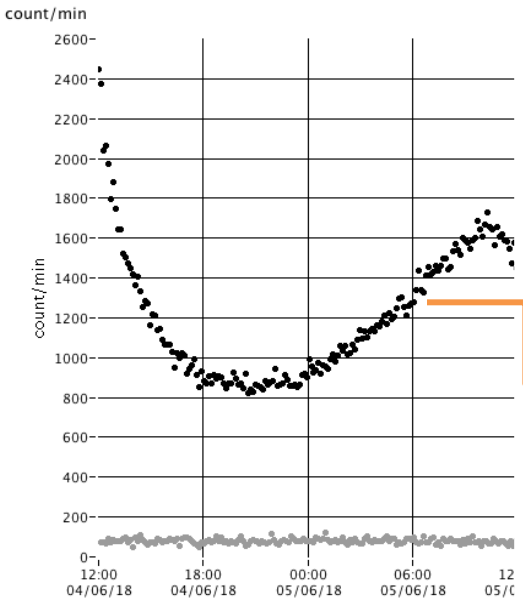
<n_{exp}>=26.83; σ^2_{exp}=29.12

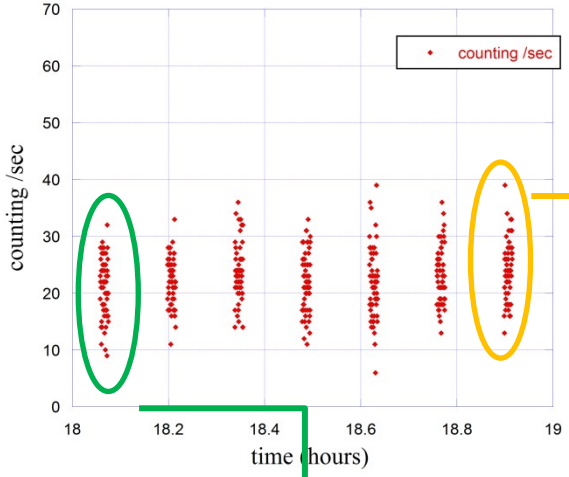


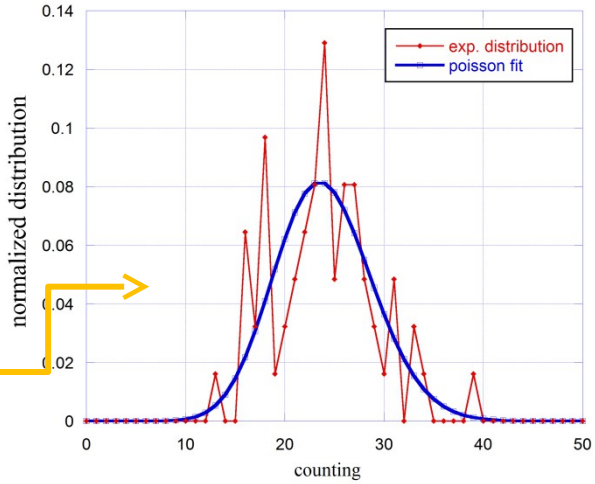
<n>=21.90±0.13

<n_{exp}>=22.21; σ^2_{exp}=24.84

Variance is always larger than mean value

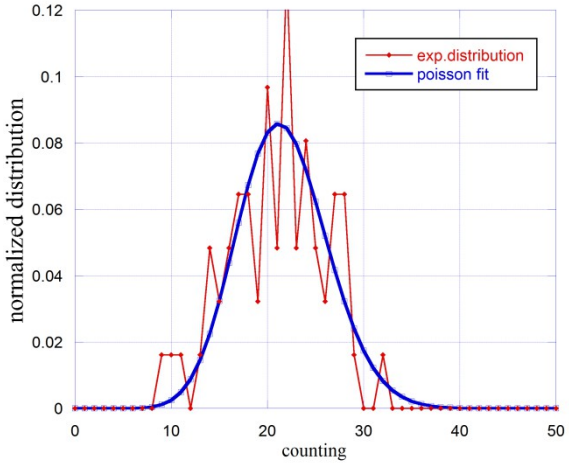






<n>=24.02±0.43

<n_{exp}>=23.87; σexp2=26.30



<n>=21.67±0.35

<n_{exp}>=20.91; σ^2_{exp}=24.59

Looking in more details
(1 minute data)

The counting distributions seem to follow a Poisson-like law, but the experimental variance is quite bigger than <n>

Could be a possible signature of non-classical nature of the light emission?

It is very difficult to say because we should measure the coherence lenght and time of the emission, but this is quite difficult due to the very low intensity of biophoton

M.Cifra, Ch. Brouder, M. Nerudova, O. Kucera , Journal of Luminesce 164, 38-51 (2015)

Biophotons: low signal/noise ratio reveals crucial events

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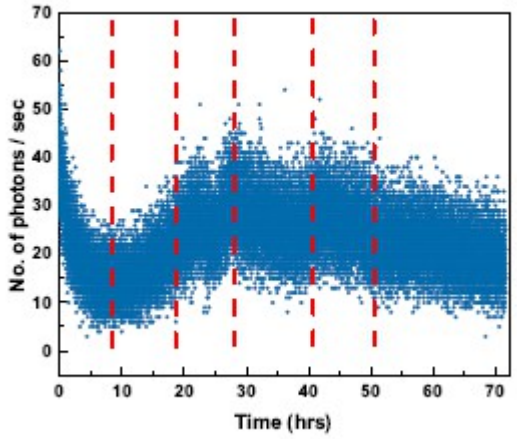
We are looking for the presence of crucial events using the Diffusion Entropy Analysis with the stripes method

BioRχiv 10.1101/558353

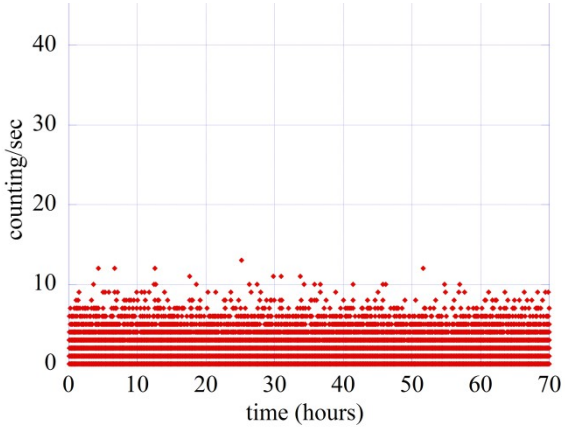
The time series n(t) is converted into a generator of diffusion and we determine the scaling factor δ of the diffusion variable x(t)

$$x(t) \propto t^{\delta}$$

δ different from 0.5 indicates that the time series transport information



δ goes from 0.79 to 0.69 according the different time regions



δ is of the order of 0.51-0.53

$$\mu = 1 + \frac{1}{\delta}$$

Where μ is related to the waiting time τ distribution density

$$\psi(\tau) \propto \frac{1}{\tau^{\mu}}$$

where τ is the time distance between two consecutive crucial events – in our case μ goes from 2.29 to 2.44 - much less than 3 which is the border between the white noise and the presence of crucial events.

Some points

- The frequency dependence behaviour shows a stronger emission in the energy window 550-645 nm (≈ 2.2-1.9 eV) in agreement with the Colli e Facchini results.

- The count distributions analysis is not able to asses a reliable evidence of coherence or nonclassicality of biophoton emission.

- The time series analysis revels the presence of crucial events.

- Different sets of same samples produce similar results although not equal – living organisms are unique!

Next

- New experimental set-up to increase the signal/noise ratio - integrating sphere
- One, two… more seeds to study crucial events in different cases
- New set of filters to decrease the energy window size
- Experiment with different Δt in order to check in detail the $p(n,\Delta t)$
- Experiments with external perturbation (for example atmospheric composition - oxygen / nitrogen ratio)
- Experiments with aerobic and non-aerobic bacteria and yeast

Any suggestion?

Why?

- The emitted radiation can be used as a non-destructive way to study the state of the living system.

- Try to better understand the origin and reason of this phenomenon – in particular do cells use also the EM emission to communicate?

In collaboration with

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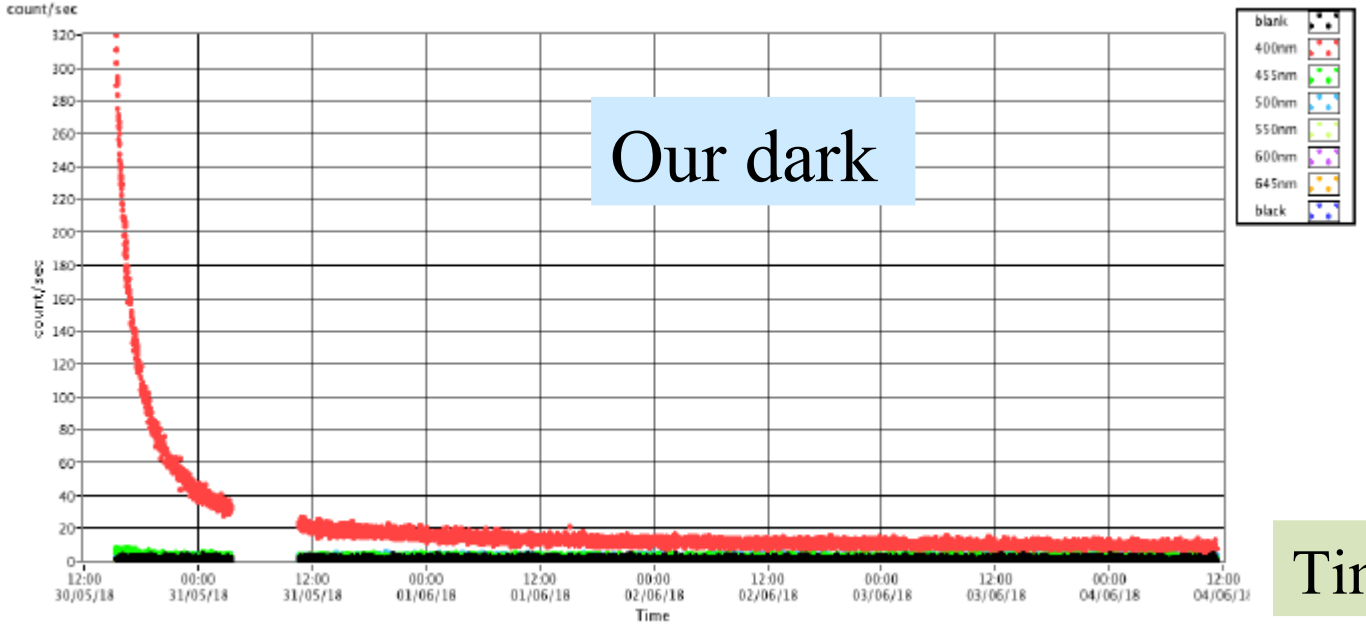
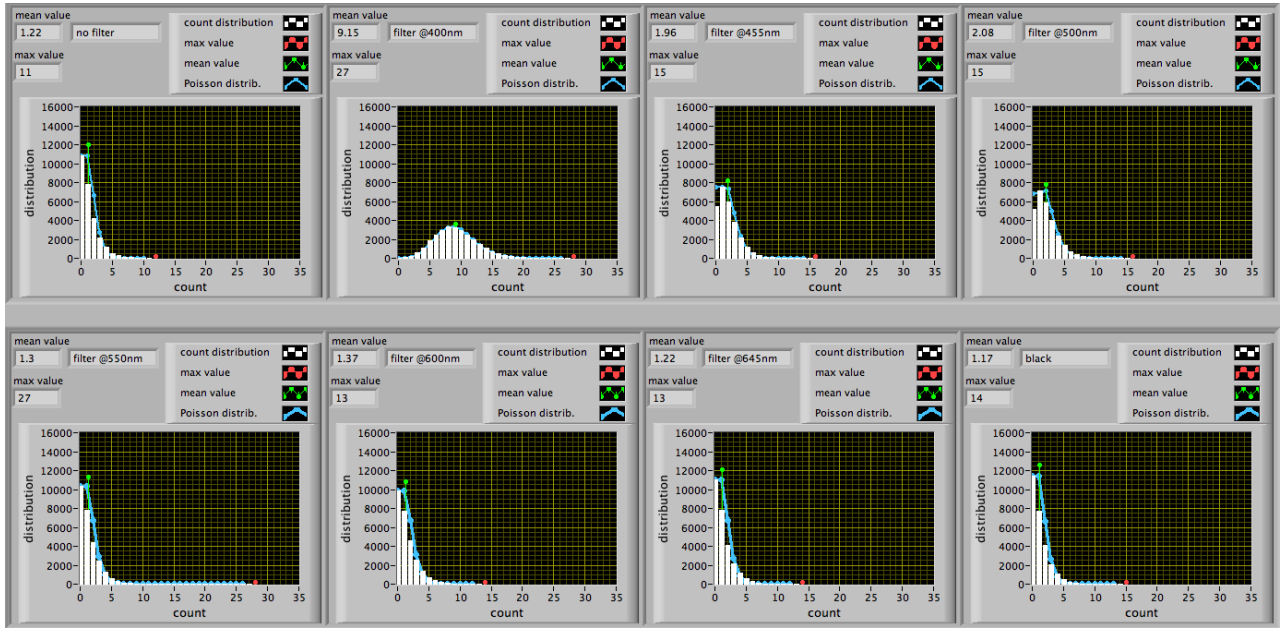
We can easily forgive a child who is afraid of the dark; the real tragedy of life is when men are afraid of the light.

— Plato



Time - hours



Count distribuition $p(n,\Delta t)$ – Δt=1 sec.

Poisson distributions with an average values of about 2 counts/sec – only the filter at 400 nm has a sizeable emission of about 9 counts/sec