

## Studying Protein kinases PKC $\zeta$ and PKM $\zeta$ with the Resonant Recognition Model. Implications for the study of Memory Mechanisms

### Estudio de proteínas quinasas PKC $\zeta$ y PKM $\zeta$ mediante el Modelo de Reconocimiento Resonante. Implicaciones para el estudio de los Mecanismos de Memoria

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#### ABSTRACT

PKM $\zeta$  is a brain-specific protein kinase that has been suggested as playing a key role in memory consolidation mechanisms. It is identical to catalytic portion of another protein kinase, PKC $\zeta$ . Lacking the regulatory end, PKM $\zeta$  is several times more active than PKC $\zeta$ . However, knowledge about PKM $\zeta$  mechanisms in memory consolidation is patchy, and sometimes contradictory. The resonant recognition model (RRM) might shed some light in understanding PKM $\zeta$  role on memory consolidation. This is the first attempt in literature to apply the RRM to the study of PKM $\zeta$  and PKC $\zeta$ . We obtained that PKM $\zeta$  presents a spectral peak at the resonant recognition frequency of  $f_{RRM} = 0.063$  (likely, corresponding to the infrared frequency of 3190 nm) and another peak at  $f_{RRM} = 0.211$  (950 nm in the near infrared). Peak at  $f_{RRM} = 0.063$  is also shared by PKC $\zeta$ , and the peak at  $f_{RRM} = 0.211$  is similar to the one recently reported in literature for regulatory proteins. We hypothesize that irradiating with a weak light infrared source at these frequencies would modify long term potentiation results. Finally, a scheme for resonant interactions in PKM $\zeta$  and PKC $\zeta$  is proposed.

**Palabras claves:** long term potentiation, protein kinases, resonant recognition model, bioinformatics.

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#### RESUMEN

PKM $\zeta$  es una proteína quinasa específica del cerebro que se ha sugerido que desempeña un papel clave en los mecanismos de consolidación de la memoria. Es idéntica a la porción catalítica de otra proteína quinasa, PKC $\zeta$ . Al carecer de la porción reguladora, PKM $\zeta$  es varias veces más activa que PKC $\zeta$ . Sin embargo, el conocimiento sobre los mecanismos de PKM $\zeta$  in en la consolidación de la memoria es parcial, y a veces contradictorio. El modelo de reconocimiento resonante (RRM) podría esclarecer la comprensión del papel de PKM $\zeta$  en la consolidación de la memoria. Este es el primer intento en la literatura para aplicar el MRR al estudio de

PKM $\zeta$  y PKC $\zeta$ . Se obtuvo que PKM $\zeta$  presenta un pico espectral a la frecuencia de reconocimiento resonante  $f_{RRM} = 0,063$  (probablemente, correspondiente a la frecuencia infrarroja de 3190 nm) y otro pico a  $f_{RRM} = 0,211$  (950 nm en el infrarrojo cercano). Pico en  $f_{RRM} = 0,063$  es también compartida por PKC $\zeta$ , y el pico a  $f_{RRM} = 0,211$  es similar a la recientemente informado en la literatura para las proteínas reguladoras. Se plantea la hipótesis de que la irradiación con una fuente de luz infrarroja débil a estas frecuencias podría modificar los resultados de potenciación a largo plazo. Finalmente, se propone un esquema para interacciones resonantes en PKM $\zeta$  y PKC.

**Key words:** potenciación a largo plaz, proteínas kinasas, modelo de reconocimiento resonante, bioinformática.

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## Introduction

Elucidation of memory mechanisms remains a central problem in Neuroscience. The discovery of long term potentiation—manifested as a substantial increase in synaptic efficacy after a tetanic stimulus—provided a model for studying memory mechanisms. Studies carried out by Eric Kandel and his group revealed that long term potentiation involves protein synthesis as well as structural changes in involved synapses.<sup>1</sup>

The possibility that a single molecule can be the main responsible for memory processes was suggested by Todd Sacktor, who found that PKM $\zeta$  (a brain-specific protein kinase devoid of regulatory pseudo-substrate portion) is the responsible for triggering a cascade of events leading to sustained self-maintenance of up-regulated synaptic efficacy.<sup>2</sup> Thus it has been suggested that inhibition of PKM $\zeta$  in the hippocampus, insular cortex, and amygdala erases several types of memories such as place memory, conditioned taste aversion, and fear memory, respectively, as well as counters long term potentiation.<sup>3</sup>

Proposed scenarios for PKM $\zeta$  mechanisms touch interaction of this protein with other proteins, as CREB-binding protein (CBP), the adaptor protein importin- $\alpha$ , the peptide ZIP, can be viewed under the light of protein interactions.<sup>4</sup> A universal mechanism has been proposed for protein interactions that offers an alternative way to traditional views.

Thus Irena Cosic has developed the Resonant Recognition Model (RRM). According to this model, bio-photons are sent by proteins and can be recognized by substrates and receptors as well as by proteins participating in a common biological function. Proteins with a common biological function do share the same frequency, whereas interacting proteins share the same frequency and opposite phase. We found no reports about RRM studies with PKM $\zeta$ . We hypothesize that a RRM study on this protein could suggest new possibilities to appraise its role in memory consolidation.

## Methods

### Data:

In order to perform RRM analysis, a group of sequences were downloaded from UNIPROT at [www.uniprot.org](http://www.uniprot.org)

### PKMζ:

PKMζ is the C-terminal fragment of the brain-specific protein kinase PKCζ corresponding to amino acids positions from 184 to 592 (see Table 1). Lacking inhibition from the pseudo-substrate of the regulatory domain of PKCζ, PKMζ is a persistently active enzyme. Although PKM is usually thought of as a cleavage product of full-length PKC it has been reported that PKM is not formed in LTP by proteolysis but by gene expression of a brain-specific PKM mRNA, which is generated by an internal promoter within the PKC gene.<sup>5</sup> Apparently Tetanic stimulation induces protein synthesis from the PKM mRNA, persistently increasing the levels of the kinase during LTP maintenance.

**Table 1.** Representation of human PKC and PKM sequences. Red color corresponds to the PKMζ domain. Modified from [www.proqinase.com](http://www.proqinase.com)

MPSRTGPKME	GSGGRVRLK A	HYGGDIFITS	VDAATTFEEL	CEEVRDMCRL
HQQHPLTLK W	VDSEGDPTV	SSQMELEEF	RLARQCRDEG	LIHVFSTP
EQPGLPCPGE	DKSIYRRGAR	RWRKLYRAN G	HLFQAKRFNR	RAYCGQCSER
IWGLARQGYR	CINCKLLVHK	RCHGLVPLTC	RKHMDVMP	QEPPVDDKNE
DADLPSEETD	GIAYISSRK	HDSIKDDSED	LKPVIDGMDG	IKISQGLGLQ
DFDLIRVIGR	GSYAKVLLVR	LKKNDQIYAM	KVVKELVHD	DEDIDWVQTE
KHVFEQASSN	PFLVGLHSCF	QTTSRFLVI	EYVNGGDLMF	HMQRQRKLPE
EHARFYAAEI	CIALNFLHER	GIIYRDLKLD	NVLLDADGHI	KLTDYGMCKE
GLGPGDTTST	FCGTPNYIAP	EILRGEEYGF	SVDWWALGV L	MFEMMAGRS P
FDIITDNPDM	NTEDYLFQVI	LEKPIRIPRF	LSVKASHVLK	GFLNKDPKER
LGCRPQTGFS	DIKSHAFFRS	IDWDLLEKKQ	ALPPFPQIT	DDYGLDNFDT
QFTSEPVQLT	PDDEDAIKRI	DQSEFEGFEY	INPLLLSTEE	SV

For resonant frequencies identification, several proteins sharing the same function were studied. Here we analyzed both PKCζ and PKMζ sequences from the following twelve species:

1. U3IRA8 (U3IRA8\_ANAPL) Anas platyrhynchos (Mallard) (Anas boschas) **ánade real**
2. U3K4C5 (U3K4C5\_FICAL) Ficedula albicollis (Collared flycatcher) (Muscicapa albicollis) **papamoscas collarino**
3. E1BQN6 (E1BQN6\_CHICK) Gallus gallus (Chicken) **gallo/ gallina**
4. G3RB70 (G3RB70\_GORGO) Gorilla gorilla gorilla (Western lowland gorilla) **gorila occidental de llanura o planicie**
5. G3TKV6 (G3TKV6\_LOXAF) Loxodonta africana (African elephant) **elefante africano de sabana**

6. G1MTR8 (G1MTR8\_MELGA) Meleagris gallopavo (Common turkey) **pavo salvaje**
7. H0WJ10 (H0WJ10\_OTOGA) Otolemur garnettii (Small-eared galago) (Garnett's greater bushbaby) **gálago de Garnet**
8. K7FJG4 (K7FJG4\_PELSI) Pelodiscus sinensis (Chinese softshell turtle) (Trionyx sinensis) **tortuga de caparazón blando de China**
9. H0YXM1 (H0YXM1\_TAEGU) Taeniopygia guttata (Zebra finch) **pinzón cebra**
10. Q05513 (KPCZ\_HUMAN) Homo sapiens (Human) **humano**
11. Q02956 (KPCZ\_MOUSE) Mus musculus (Mouse) **ratón común**
12. P09217 (KPCZ\_RAT) Rattus norvegicus (Rat) **rata parda**

Each PKMC sequence in these twelve species contained exactly 592 amino acids. The PKM $\zeta$  sequence was obtained from corresponding PKC $\zeta$  by extraction of the fragment with amino acids from 184 to 592.

For comparison, the PKCZ segment from position 1 to 183 (containing the regulatory unit and the hinge) was also submitted to RRM analysis.

#### *Resonant Recognition Model*

The RRM, proposed by Irena Cosic, postulates that interactions of proteins with receptors, peptide substrates and other proteins are achieved through resonant energy transfer between involved molecules at the frequency specific for each observed function/interaction.<sup>6</sup> This transfer of bio-photons at energies of the order of  $10^{-20}$  J is the universal mechanism by which macromolecules and smaller peptides recognize each other.<sup>7</sup> This vision is radically different from the idea of interactions of through van der Waals forces, hydrogen bonds and structural complementarity as the main role players in the molecular recognition by proteins. A key aspect of the RRM approach is to represent a protein's primary structure as a numerical series. For this, each amino acid in the sequence is symbolized with the (numerical) value of a biologically relevant physical-chemical parameter. If the chosen parameter is suitable, it happens that proteins with the same biological function have a common frequency component in their Fourier spectra. This common frequency is considered to be a hallmark of a protein's biological function/interaction. After trying with different candidate parameters, it was found that the energy of delocalized electrons, calculated as the electron-ion interaction pseudo-potential (EIIP) of each amino acid residue is the best suited quantity for RRM analysis.<sup>8</sup> EIIP values for each amino acid appear in Table 2. The EIIP parameter describes the average energy states of all valence electrons in a particular amino acid. Accordingly, the resulting numerical series represents the distribution of the free electron energies along protein's backbone.

Once the numerical sequence is obtained, it is submitted to spectral analysis using the Fourier Transform (FT) to extract information pertinent to the biological function. In the frequency domain, the FT of an individual protein sequence will contain nonzero values for many frequencies.<sup>9</sup>

However, if a cross spectral function is estimated for a group of proteins sharing one common frequency, the cross spectral function will have a nonzero value at this resonant frequency.

Since it can be expected that a given protein can display more than one function, it may happen that the cross spectrum of a group of orthologous proteins will exhibit more than one peak.

The multiple cross-spectral function obtained from a group of orthologous sequences with the same biological function has been named 'consensus spectrum'. The presence of a distinct peak frequency in a consensus spectrum implies that this common frequency is related to the shared biological function provided the following criteria are met:

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- One peak only exists for a group of protein sequences sharing the same biological function;
- No significant peak exists for biologically unrelated protein sequences;
- Peak frequencies are different for different biological functions.

Cosic has studied a large amount of proteins and concluded that each specific biological function of a given protein characterized by a single frequency. The RRM can be applied to the study of interactions of proteins with their targets (receptors, ligands and inhibitors) since it was found that interacting proteins and targets display the same characteristic frequency in their interactions.<sup>6</sup> Thus, the RRM characteristic frequencies represent a protein's general functions as well as the mutual recognition between a particular protein and its target (receptor, ligand, etc.). As this recognition arises from the matching of periodicities within the distribution of energies of free electrons along the interacting proteins, it can be regarded as the resonant recognition.

It has been found that peptides attaching to proteins do share the same resonant frequency and exhibit opposite phase. Thus, abiding these two conditions is regarded as a hallmark for protein-protein interaction.

The primary amino acid sequences were transformed into a numerical series following the Resonant Recognition Model (RRM) methodology. For it, to each of the 20 amino acids in the entire sequence an electron-ion interaction potential (EIIP) value was assigned (Table 2).

**Table 2.** EIIP values for each amino acid

Amino Acid	EIIP
S	0.0829
T	0.0946
Q	0.0761
Y	0.0516
G	0.005
A	0.0373
V	0.0057
L	0.0000
I	0.0000
C	0.0829
M	0.0823
P	0.0198
F	0.0946
W	0.0548
K	0.0371
D	0.1263
E	0.0058
R	0.0959
H	0.0242
N	0.0036

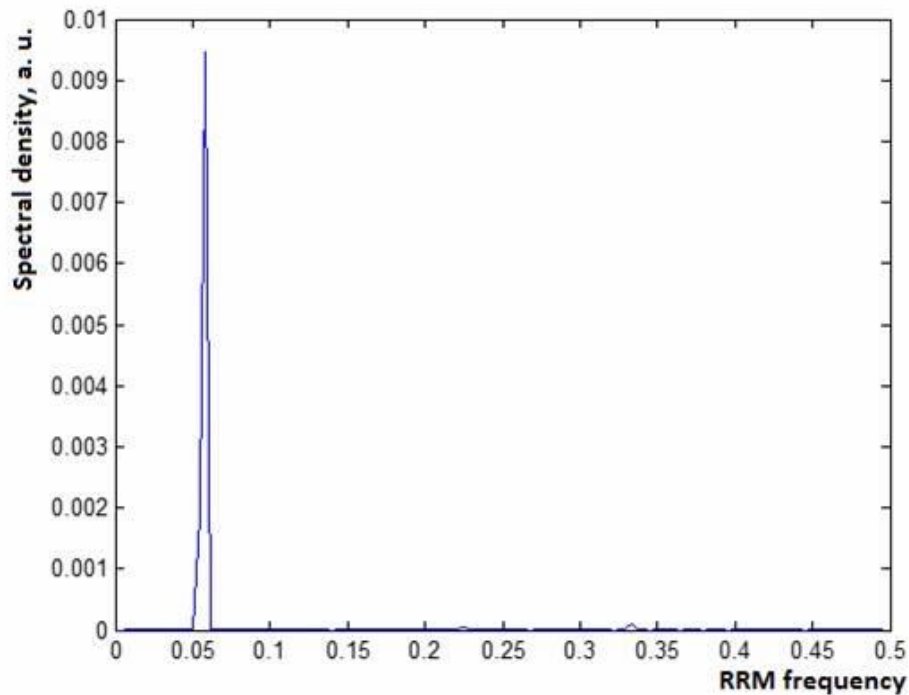
The obtained numerical series was treated as a time series. Power spectrum was estimated for each sequence using a SciLab program based on Fourier analysis. For finding the consensus spectrum, all the twelve spectral vectors were submitted to scalar cross multiplication. The obtained product is considered as the consensus spectrum.

The RRM frequency was converted to a true electromagnetic frequency by determining the appropriate wavelength using the empirical function proposed by Cosic:  $f_{RRM} = 201/\lambda$ .

## Results

*PKCζ*. As apparent from Figure 1, a clear single peak was found at the frequency of  $f_{RRM} = 0.063$ . Unlike many other protein sequences, this protein kinase exhibits only

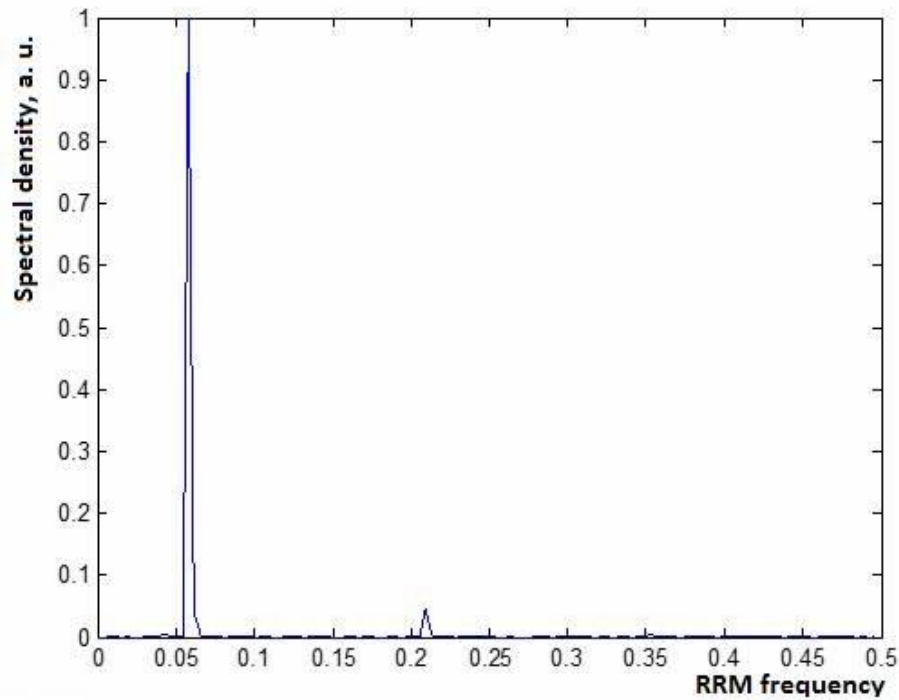
one prominent peak. Likely, this would correspond to the infrared frequency of 3190 nm.



**Figure 1:** Consensus spectrum for PKC $\zeta$ . A prominent single peak appears at  $f_{RRM} = 0.063$ . Spectral density values at figures 1, 2, and 3 appear at the same scale

*PKM $\zeta$* . We obtained, that PKM $\zeta$  shares some features of PKC $\zeta$  whereas differing in others (Figure 2). As observed, PKM $\zeta$  shows a prominent peak at the same frequency of  $f_{RRM} = 0.063$ . However, when amplitudes were compared, the peak seems to be more than 100 times higher. At the same time, a smaller second peak appears at  $f_{RRM} = 0.211$  (950 nm in the near infrared).



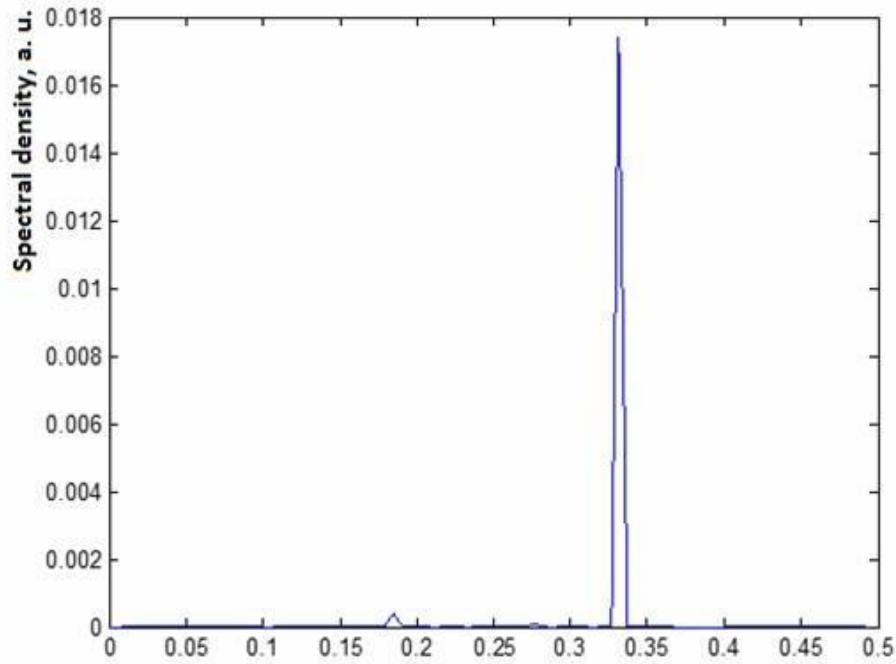


**Figure 2:** Consensus spectrum for PKM $\zeta$ . A prominent peak appears at  $f_{RRM}=0.063$ , followed by a smaller peak at  $f_{RRM}=0.22$ , comparison with Figure 1 shows that spectral density of the peak at  $f_{RRM}=0.063$  is higher than that corresponding to PKC $\zeta$  in more than 100 times. Spectral density values at figures 1, 2, and 3 appear at the same scale

### Regulatory+Hingedomains

As it can be seen from figure 3, the regulatory domain with the hinge exhibit a peak at  $f_{RRM}=0.33$ , corresponding to 609 nm (yellow light).

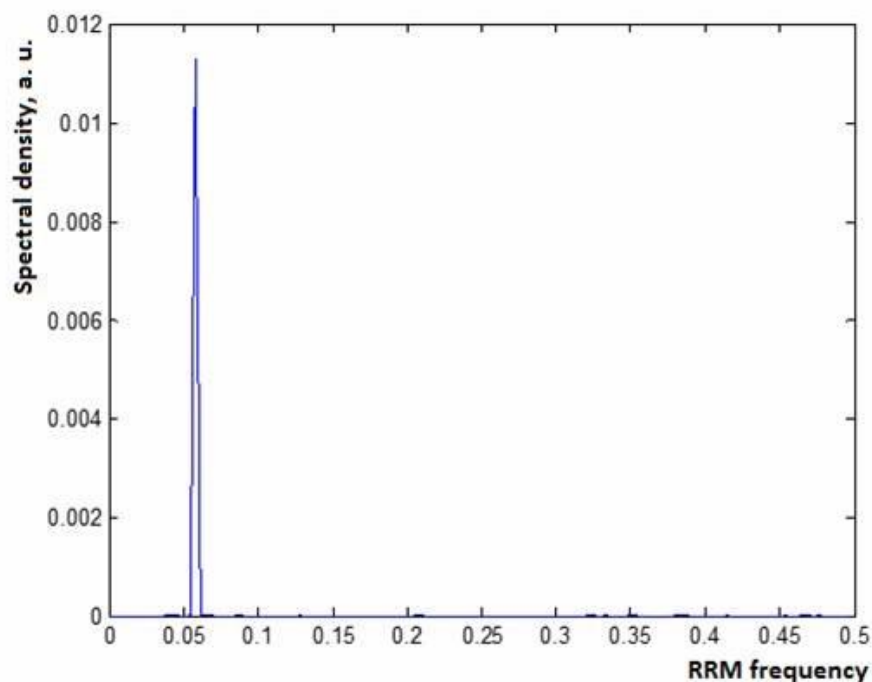




**Figure 3:** Consensus spectrum for PKC $\zeta$  regulatory domain and hinge (amino acids from position 1 to 183; see Table 1). A prominent single peak appears at  $f_{RRM} = 0.33$ . Spectral density values at figures 1, 2, and 3 appear at the same scale

### May regulatory unit be a "pseudo-substrate"?

A consensus spectrum was obtained from combining 12 PKM $\zeta$  and 12 sequences of the regulatory + hinge domain. As it can be noticed from figure 4 there is a peak at  $f_{RRM} = 0.063$ . This supports the idea that PKM $\zeta$  can combine with the regulatory domain even after PKC $\zeta$  cleavage.



**Figure 4:** Consensus spectrum for twelve PKC $\zeta$  regulatory domain and hinge (amino acids from position 1 to 183; see Table 1) plus twelve PKM $\zeta$ . A prominent single peak appears at  $f_{RRM} = 0.063$ . Due to differences in number of compared sequences, spectral density values are not comparable with previous figures

## Discussion

So far, RRM remains as a Hypothesis,<sup>10</sup> accepted by a small fraction of research community. However, it brings plausible predictions to a group of experimental data, such as a nice correspondence between spectral density changes and results of mutagenesis experiments, excellent correlation between theoretical  $f_{RRM}$  and absorption frequency for light-absorbing proteins, biological function of different synthetic peptides designed via RRM, as well as bio-photon emissions of proteins in solution in full accordance with the Cosic model, among others.<sup>11</sup> If proven true, Cosic's model will herald a "true revolution in bioinformatics", as suggested by Mae.

It is worth of notice that RRM analysis considers only primary structure of the protein backbone, which makes it radically different from most approaches in structural biology and bioinformatics.

Our results can be summarized as follows:

- There is a resonant frequency at  $f_{RRM} = 0.063$  that is shared by both PKC $\zeta$  and PKM $\zeta$ . This frequency is not prominent at regulatory+ hinge domains. The peak corresponding to PKM $\zeta$  is more than 100 times higher.
- A smaller, but significant peak appears at  $f_{RRM} = 0.22$ . This peak is not observable in PKC $\zeta$  nor in the regulatory + hinge domains.

- The regulatory + hinge domains may interact with PKM $\zeta$  at the resonant frequency of  $f_{RRM} = 0.063$ .

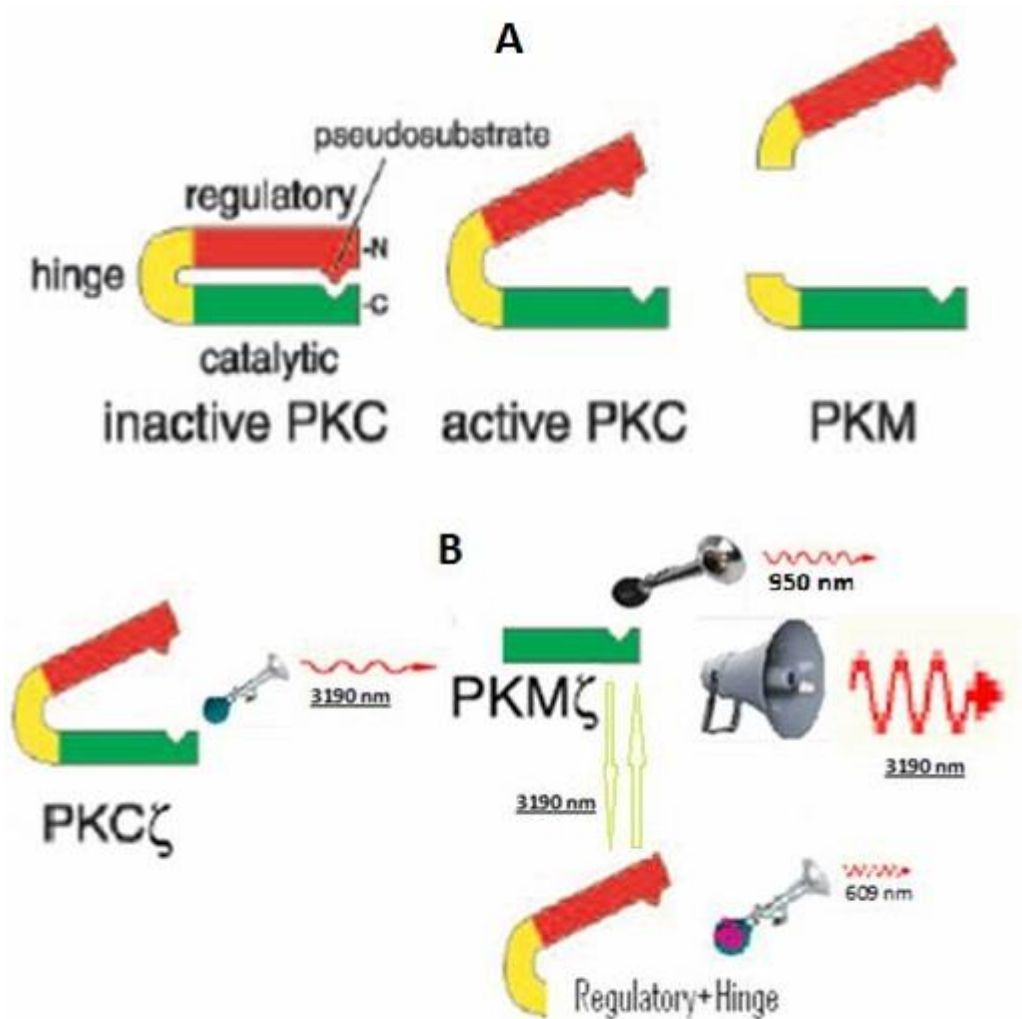
These results do agree with the idea of PKC $\zeta$  and PKM $\zeta$  sharing a common function, supported in this case by the common frequency at  $f_{RRM} = 0.063$ . This frequency is also used for recognition between PKM $\zeta$  and the regulatory unit.

It is recognized that PKM $\zeta$  is much more active than PKC $\zeta$ , and the higher amplitude of the peak could be a corroboration of this in RRM terms. However, the common view for this difference is the idea that the regulatory domain act as a pseudo-substrate for the catalytic domain. However, in RRM analysis only the primary sequence is taken into account and this is enough for suggesting marked differences in activity levels.

On the other hand, interacting proteins do share the same frequency, only with different phases. The fact that the peak at  $f_{RRM} = 0.063$  is common between regulatory+hinge domains and PKM $\zeta$  suggests that the two portions of the cleaved PKC $\zeta$  would interact leading to a reduced function. This could explain why PKM $\zeta$  is obtained in vivo by direct synthesis and not from the cleavage of PKC $\zeta$ .

Our results also suggest that the peak at  $f_{RRM} = 0.212$  (950 nm in the near infrared), is related to the function of PKM $\zeta$  as a signal protein. Dotta et al. suggested that "According to Cosic's theory to predict macromolecular bioactivity, the 950-nm band is associated with molecules involved with signaling activities within the cell as well as cell proliferation. These processes are activated by forskolin and inhibited by PD8059." <sup>7</sup> Thus this peak probably reflects the condition of PKM $\zeta$  as a signal protein, a function that is shared with PKA, and enhanced with forskolin.

Similarly, it is to be clarified which function is the peak at  $f_{RRM} = 0.33$  -observed for the regulatory and hinge domain- is associated to. In figure 5 we are comparing the classical view on PKC $\zeta$  and PKM $\zeta$  with the RRM view based on results from this work.



**Figure 5:** Comparing the classical view on PKC $\zeta$  and PKM $\zeta$  (A) with RRM-based evidence (B)

PKC $\zeta$  can be viewed as a resonance system emitting/receiving infrared light 3190 nm. PKM $\zeta$  is much more active at this main wavelength, and also is tuned to near infrared at 913 nm. The regulatory and hinge domains are tuned to yellow light (609 nm). At the same time, they do interact with PKM $\zeta$  through infrared light 3190 nm.

Further studies would involve the RRM study of proteins putatively interacting with PKM $\zeta$ , in order to elucidate if the condition of common frequency and opposite phase is met.

Finally, RRM suggest two ways of interacting with PKC $\zeta$ . One is via the design of peptides<sup>12</sup> and the other via weak electromagnetic radiation at the above-proposed wavelengths. The effect of them upon LTP could suggest new aspects of PKC $\zeta$  in memory mechanisms.)

On the light of present results it is expected that monochromatic infrared light 3190 nm should modify LTP. At this stage is difficult to predict whether the effect will be inhibiting or enhancing. Apparently the experiment would be technically affordable, either using infrared LED or Laser sources.

## Conclusion

La toma de decisiones se presenta muchas veces en los procesos administrativos, especialmente en condiciones de incertidumbre, en condiciones de riesgo y en condiciones de conflicto. En esta última la toma de decisiones resulta mucho más compleja, en el sentido que la decisión adoptada no depende únicamente del tomador de decisiones, sino además de la influencia de su oponente. Muchas son las aplicaciones de la Teoría de Juegos, entre las que destaca los juegos contra la naturaleza, ejemplificado en este trabajo a través de un problema práctico, en el que se decide invertir un presupuesto en recursos informáticos en la Facultad de Tecnología de la Salud de la Universidad de Ciencias Médicas de Santiago de Cuba para ser explotados durante el quinquenio 2016 - 2020, y para lo cual, independientemente de la plataforma informática establecida, se puedan adaptar y reutilizar al máximo.

Dicho problema fue modelado como un problema de PL, y resuelto con el apoyo del Solver, una herramienta para la solución de este tipo de problemas de optimización, incorporada en el Microsoft Excel.

Se pudo hallar una solución óptima, en el que se recomendaba invertir solamente en hardware para estaciones de trabajo, y en hardware y componentes de red, lo que garantizaría por lo menos un 72.08% de adaptación de los recursos invertidos, cualquiera que sea la plataforma informática establecida en la Facultad.

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