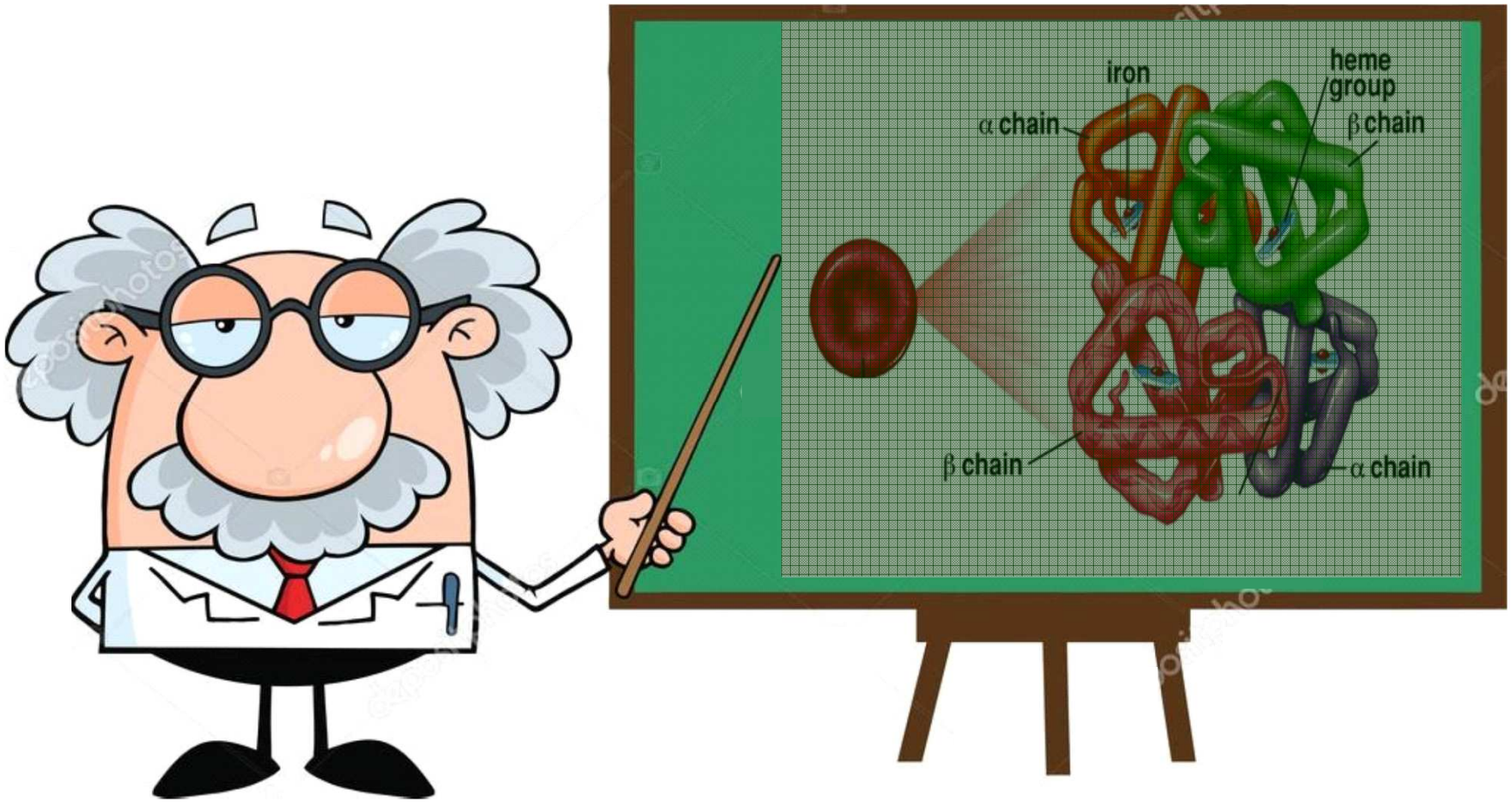
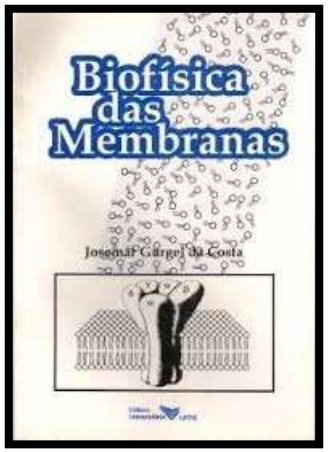
Proteínas intrinsecamente desordenadas

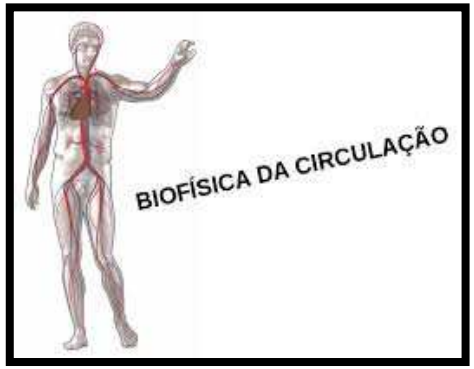
José Luiz Lopes

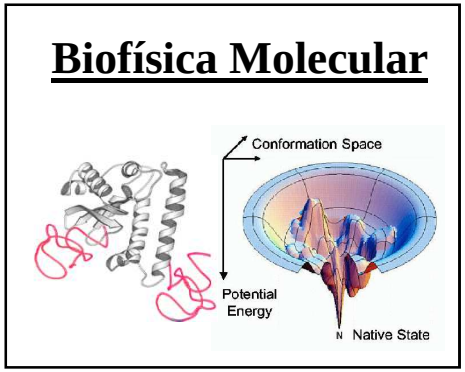
Instituto de Física, USP


iron
heme group
α chain
β chain
β chain
α chain

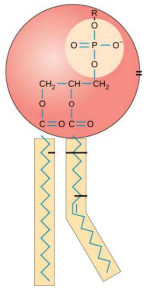
Física Biológica ou Biofísica







Biofísica Molecular



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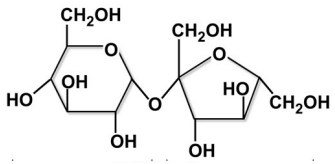

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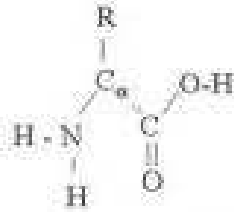
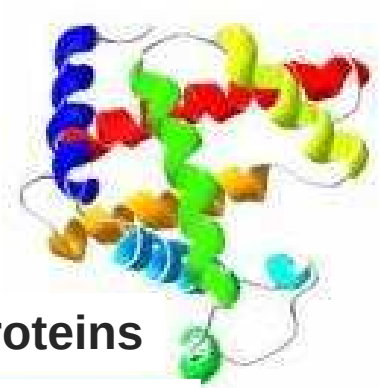
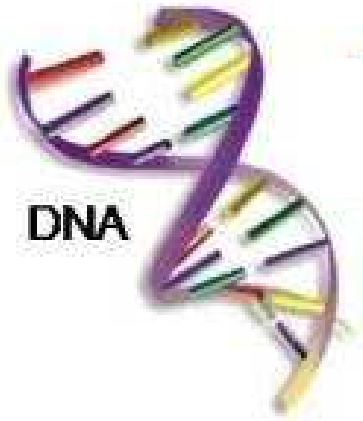


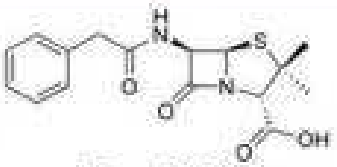
amino-acids



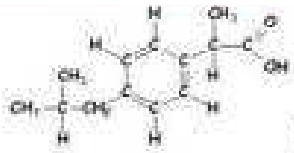
proteins



DNA

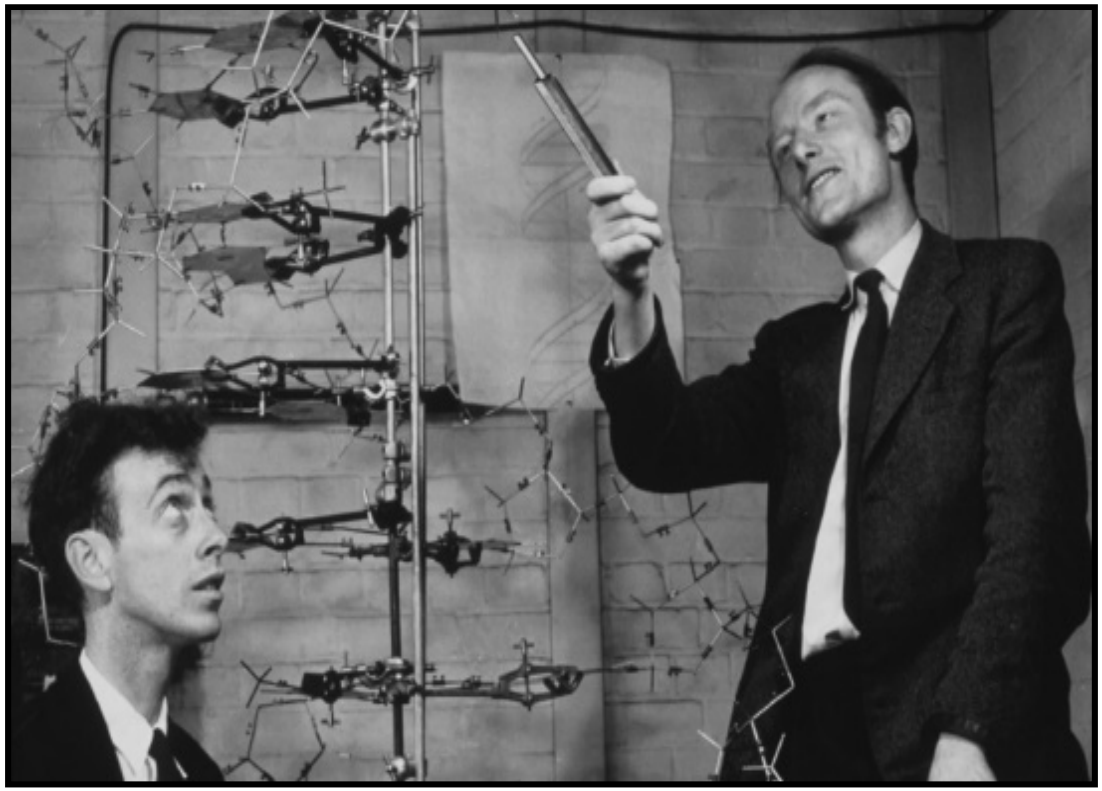


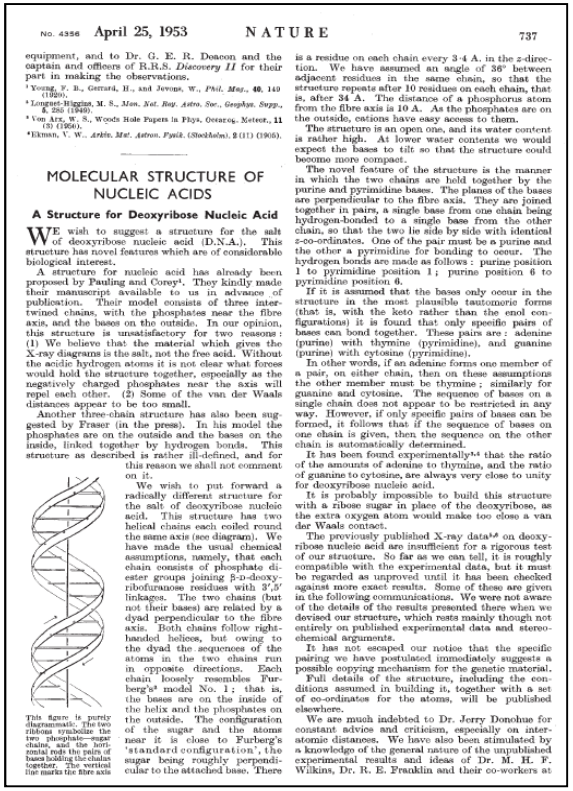
Penicillin



Ibuprofen

carbon nanotubes





No. 4356 April 25, 1953 NATURE 737

equipment, and to Dr. G. E. R. Deacon and the captain and officers of R.R.S. *Discovery II* for their part in making the observations.

¹ Young, F. B., Gerrard, H., and Jevons, W., *Phil. Mag.*, **40**, 149 (1920).
² Longuet-Higgins, M. S., *Mon. Not. Roy. Astro. Soc., Geophys. Supp.*, **5**, 285 (1949).
³ Von Arx, W. S., Woods Hole Papers in Phys. Oceanog. Meteor., **11** (3) (1950).
⁴ Ekman, V. W., *Arkiv. Mat. Astron. Fysik. (Stockholm)*, **2** (11) (1906).

MOLECULAR STRUCTURE OF NUCLEIC ACIDS

A Structure for Deoxyribose Nucleic Acid

WE wish to suggest a structure for the salt of deoxyribose nucleic acid (D.N.A.). This structure has novel features which are of considerable biological interest.

A structure for nucleic acid has already been proposed by Pauling and Corey[1]. They kindly made their manuscript available to us in advance of publication. Their model consists of three intertwined chains, with the phosphates near the fibre axis, and the bases on the outside. In our opinion, this structure is unsatisfactory for two reasons: (1) We believe that the material which gives the X-ray diagrams is the salt, not the free acid. Without the acidic hydrogen atoms it is not clear what forces would hold the structure together, especially as the negatively charged phosphates near the axis will repel each other. (2) Some of the van der Waals distances appear to be too small.

Another three-chain structure has also been suggested by Fraser (in the press). In his model the phosphates are on the outside and the bases on the inside, linked together by hydrogen bonds. This structure as described is rather ill-defined, and for this reason we shall not comment on it.

We wish to put forward a radically different structure for the salt of deoxyribose nucleic acid. This structure has two helical chains each coiled round the same axis (see diagram). We have made the usual chemical assumptions, namely, that each chain consists of phosphate diester groups joining β-D-deoxyribofuranose residues with 3′,5′ linkages. The two chains (but not their bases) are related by a dyad perpendicular to the fibre axis. Both chains follow right-handed helices, but owing to the dyad the sequences of the atoms in the two chains run in opposite directions. Each chain loosely resembles Furberg's[2] model No. 1; that is, the bases are on the inside of the helix and the phosphates on the outside. The configuration of the sugar and the atoms near it is close to Furberg's 'standard configuration', the sugar being roughly perpendicular to the attached base. There is a residue on each chain every 3·4 A. in the *z*-direction. We have assumed an angle of 36° between adjacent residues in the same chain, so that the structure repeats after 10 residues on each chain, that is, after 34 A. The distance of a phosphorus atom from the fibre axis is 10 A. As the phosphates are on the outside, cations have easy access to them.

This figure is purely diagrammatic. The two ribbons symbolize the two phosphate—sugar chains, and the horizontal rods the pairs of bases holding the chains together. The vertical line marks the fibre axis

The structure is an open one, and its water content is rather high. At lower water contents we would expect the bases to tilt so that the structure could become more compact.

The novel feature of the structure is the manner in which the two chains are held together by the purine and pyrimidine bases. The planes of the bases are perpendicular to the fibre axis. They are joined together in pairs, a single base from one chain being hydrogen-bonded to a single base from the other chain, so that the two lie side by side with identical *z*-co-ordinates. One of the pair must be a purine and the other a pyrimidine for bonding to occur. The hydrogen bonds are made as follows: purine position 1 to pyrimidine position 1; purine position 6 to pyrimidine position 6.

If it is assumed that the bases only occur in the structure in the most plausible tautomeric forms (that is, with the keto rather than the enol configurations) it is found that only specific pairs of bases can bond together. These pairs are: adenine (purine) with thymine (pyrimidine), and guanine (purine) with cytosine (pyrimidine).

In other words, if an adenine forms one member of a pair, on either chain, then on these assumptions the other member must be thymine; similarly for guanine and cytosine. The sequence of bases on a single chain does not appear to be restricted in any way. However, if only specific pairs of bases can be formed, it follows that if the sequence of bases on one chain is given, then the sequence on the other chain is automatically determined.

It has been found experimentally[3,4] that the ratio of the amounts of adenine to thymine, and the ratio of guanine to cytosine, are always very close to unity for deoxyribose nucleic acid.

It is probably impossible to build this structure with a ribose sugar in place of the deoxyribose, as the extra oxygen atom would make too close a van der Waals contact.

The previously published X-ray data[5,6] on deoxyribose nucleic acid are insufficient for a rigorous test of our structure. So far as we can tell, it is roughly compatible with the experimental data, but it must be regarded as unproved until it has been checked against more exact results. Some of these are given in the following communications. We were not aware of the details of the results presented there when we devised our structure, which rests mainly though not entirely on published experimental data and stereochemical arguments.

It has not escaped our notice that the specific pairing we have postulated immediately suggests a possible copying mechanism for the genetic material.

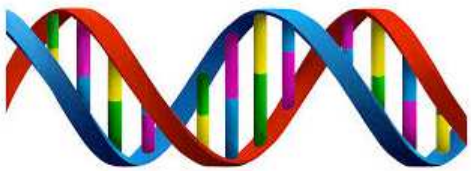
Full details of the structure, including the conditions assumed in building it, together with a set of co-ordinates for the atoms, will be published elsewhere.

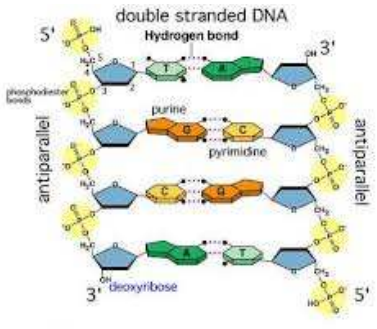
We are much indebted to Dr. Jerry Donohue for constant advice and criticism, especially on interatomic distances. We have also been stimulated by a knowledge of the general nature of the unpublished experimental results and ideas of Dr. M. H. F. Wilkins, Dr. R. E. Franklin and their co-workers at

Watson e Crick, 1953

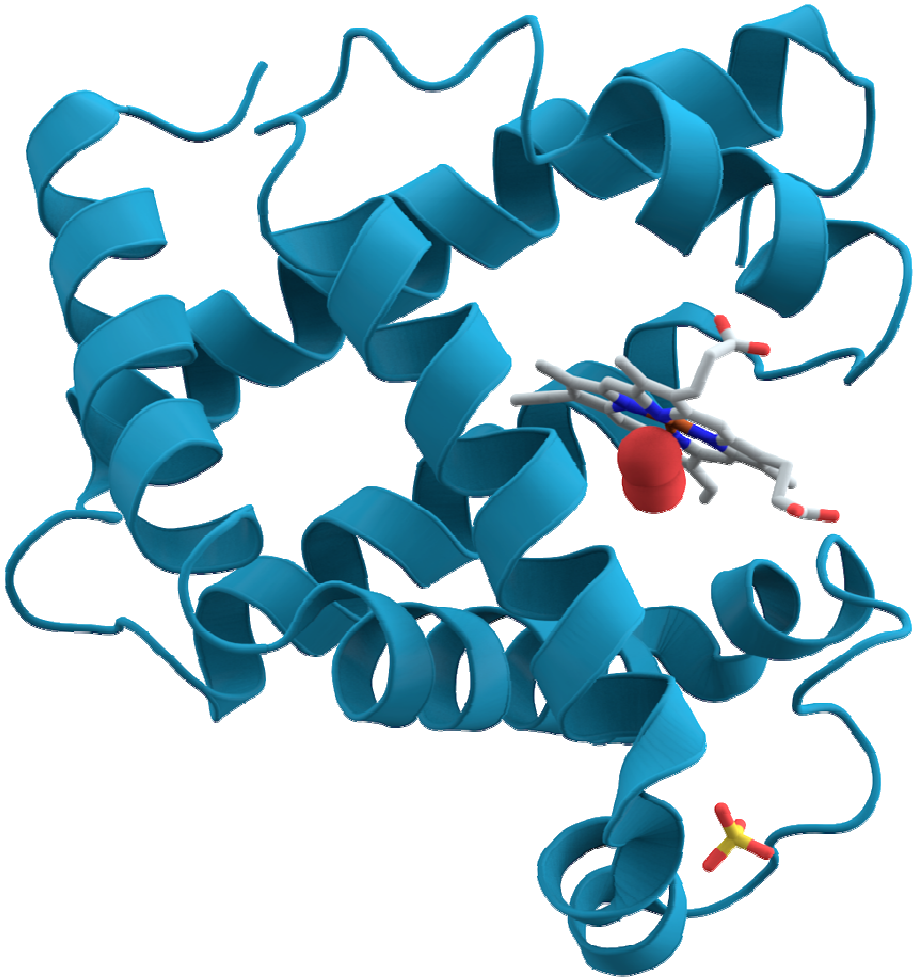
Nobel 1962

Nature 171: 737-738 (1953)

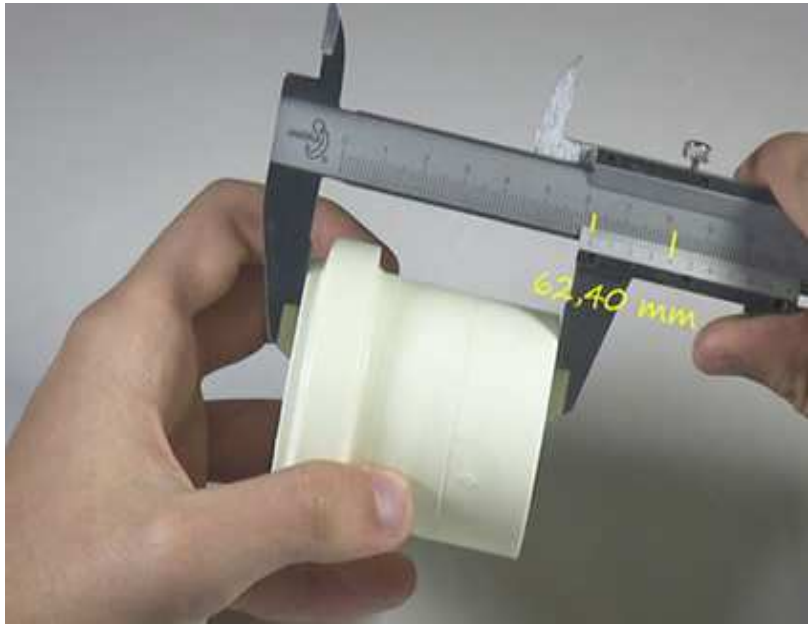


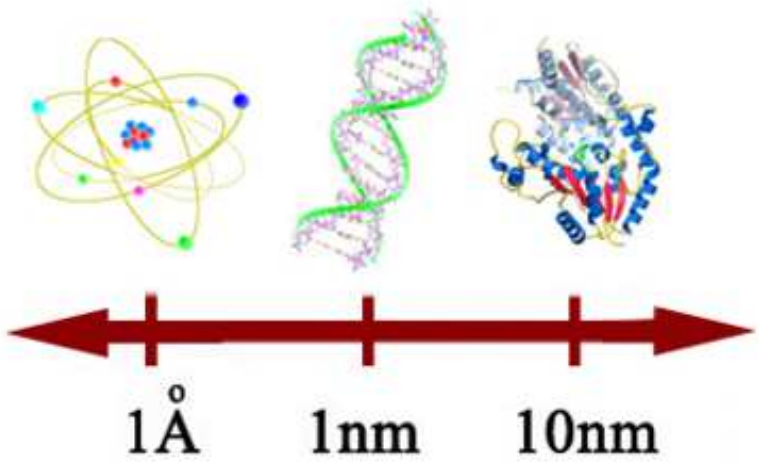


Biologia Estrutural

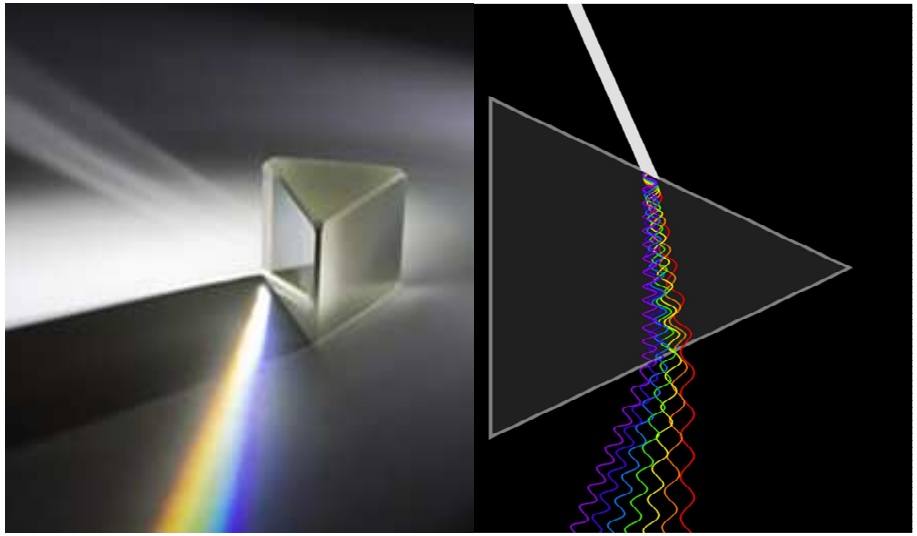


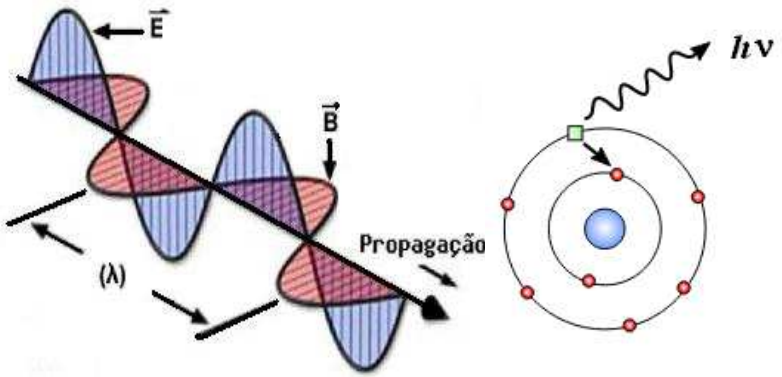
Como estudar?

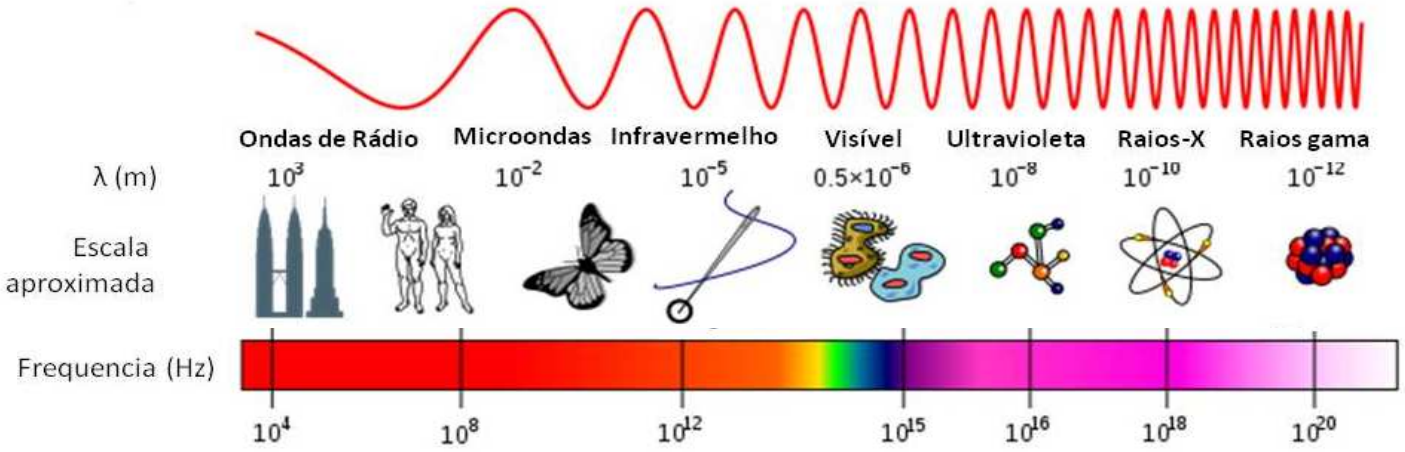


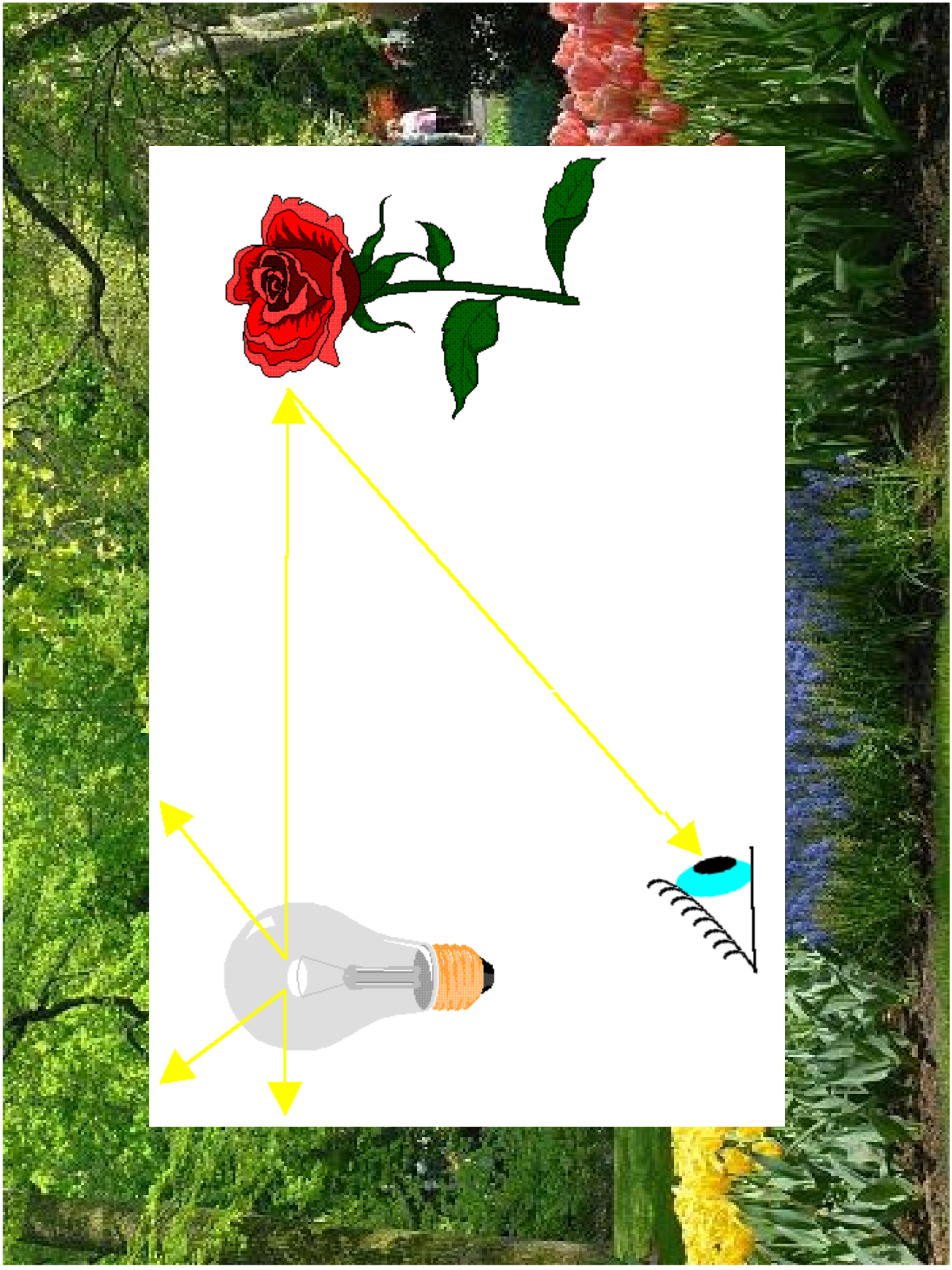


Radiação eletromagnética

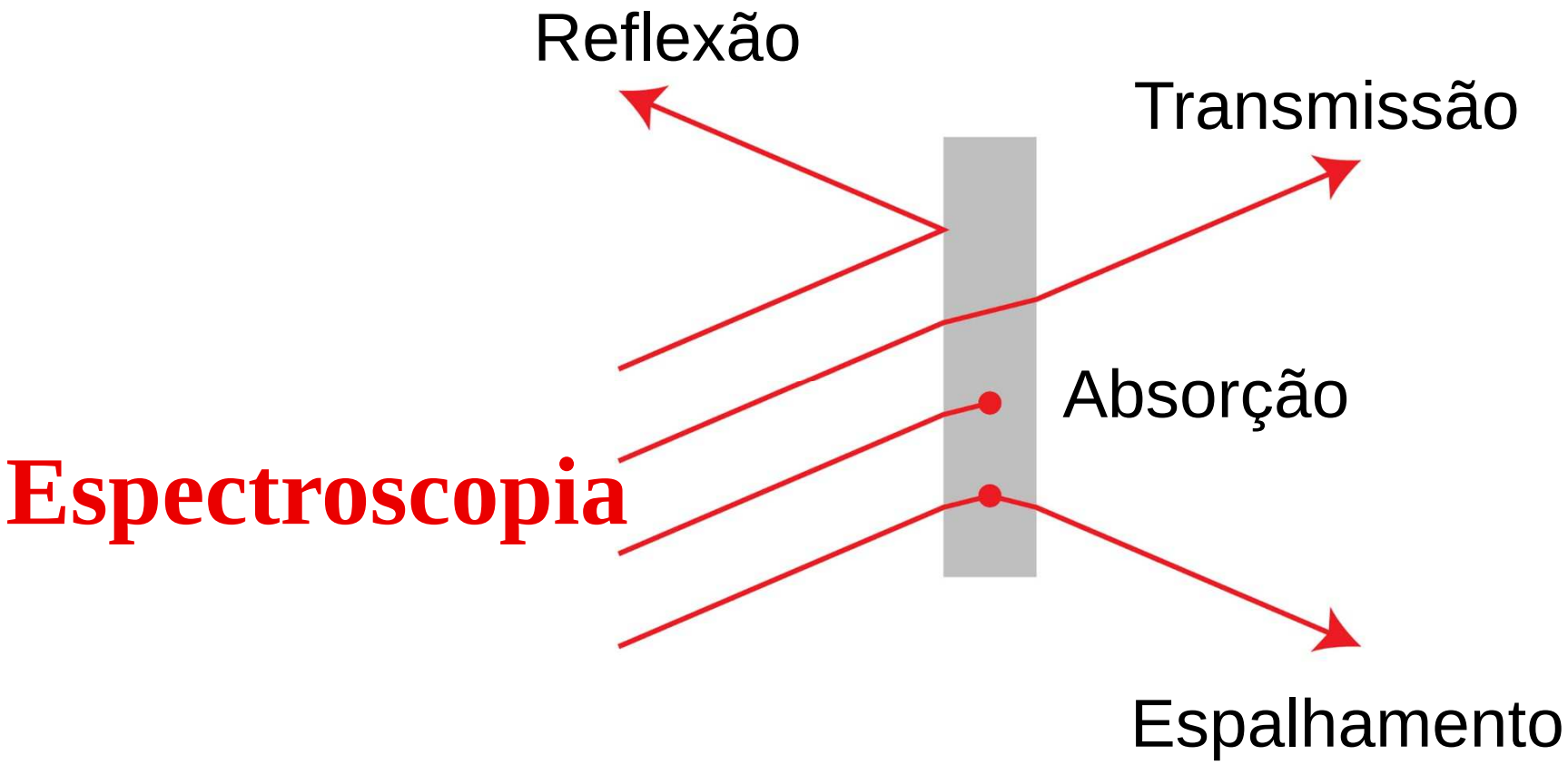






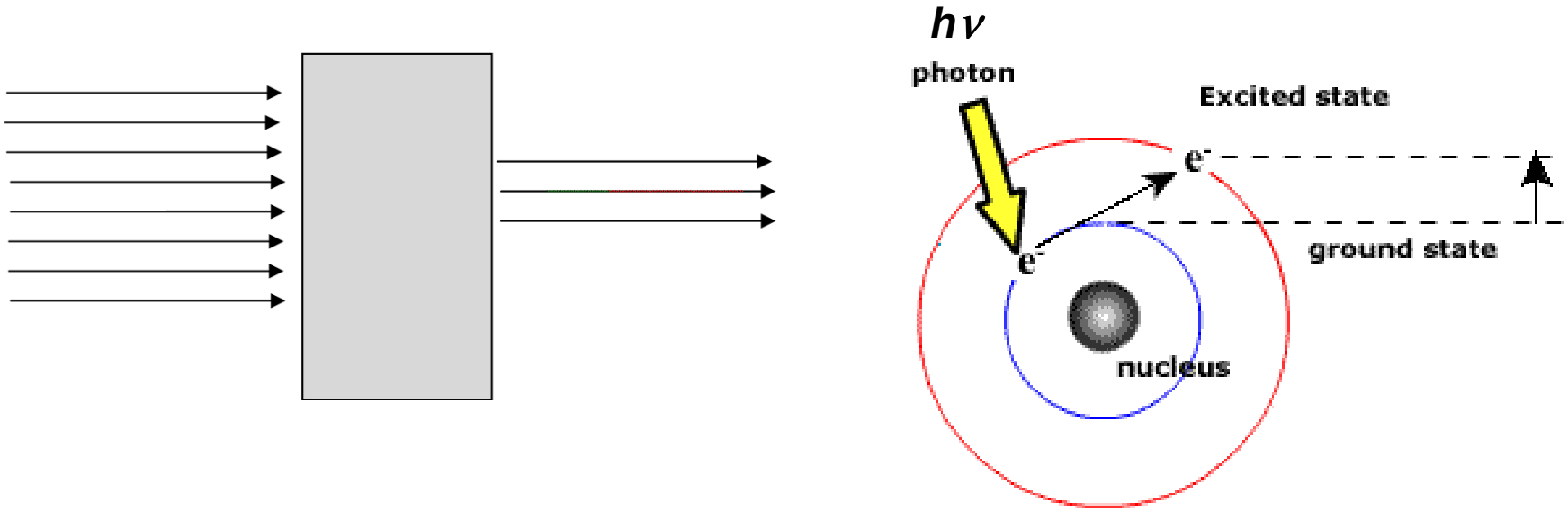


Interação Luz-Matéria

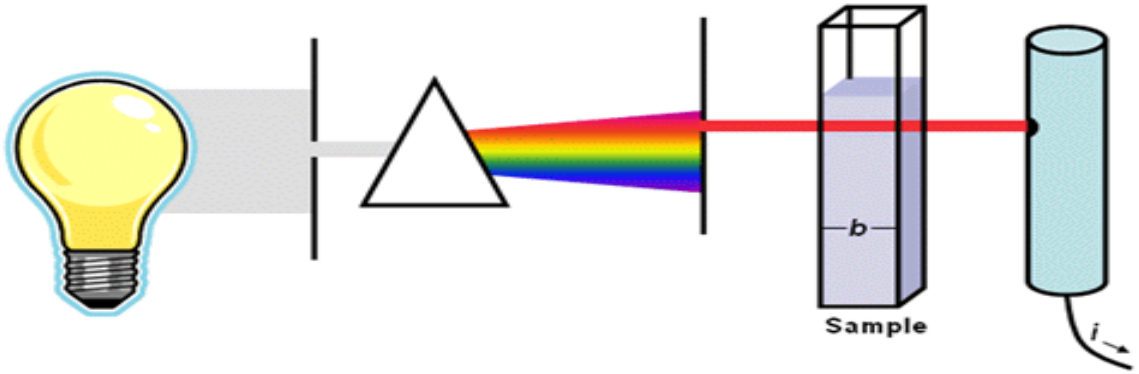


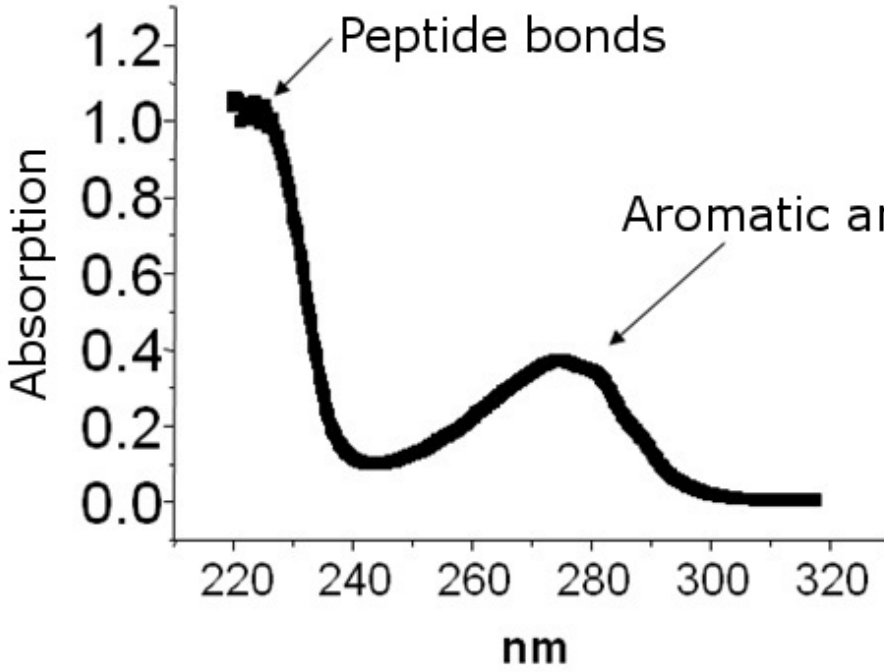
Espectroscopia

Absorção de Luz



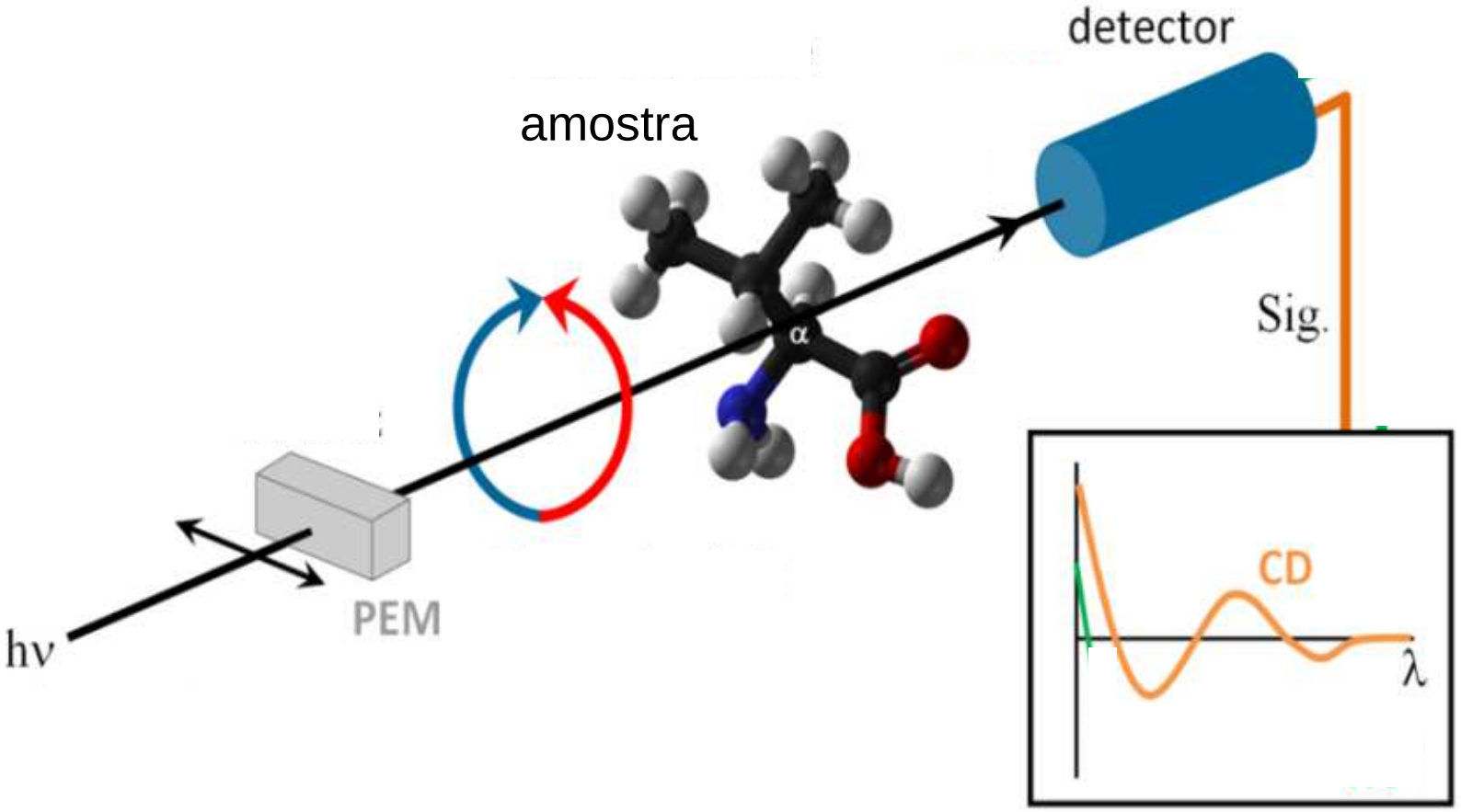
Absorção de Luz



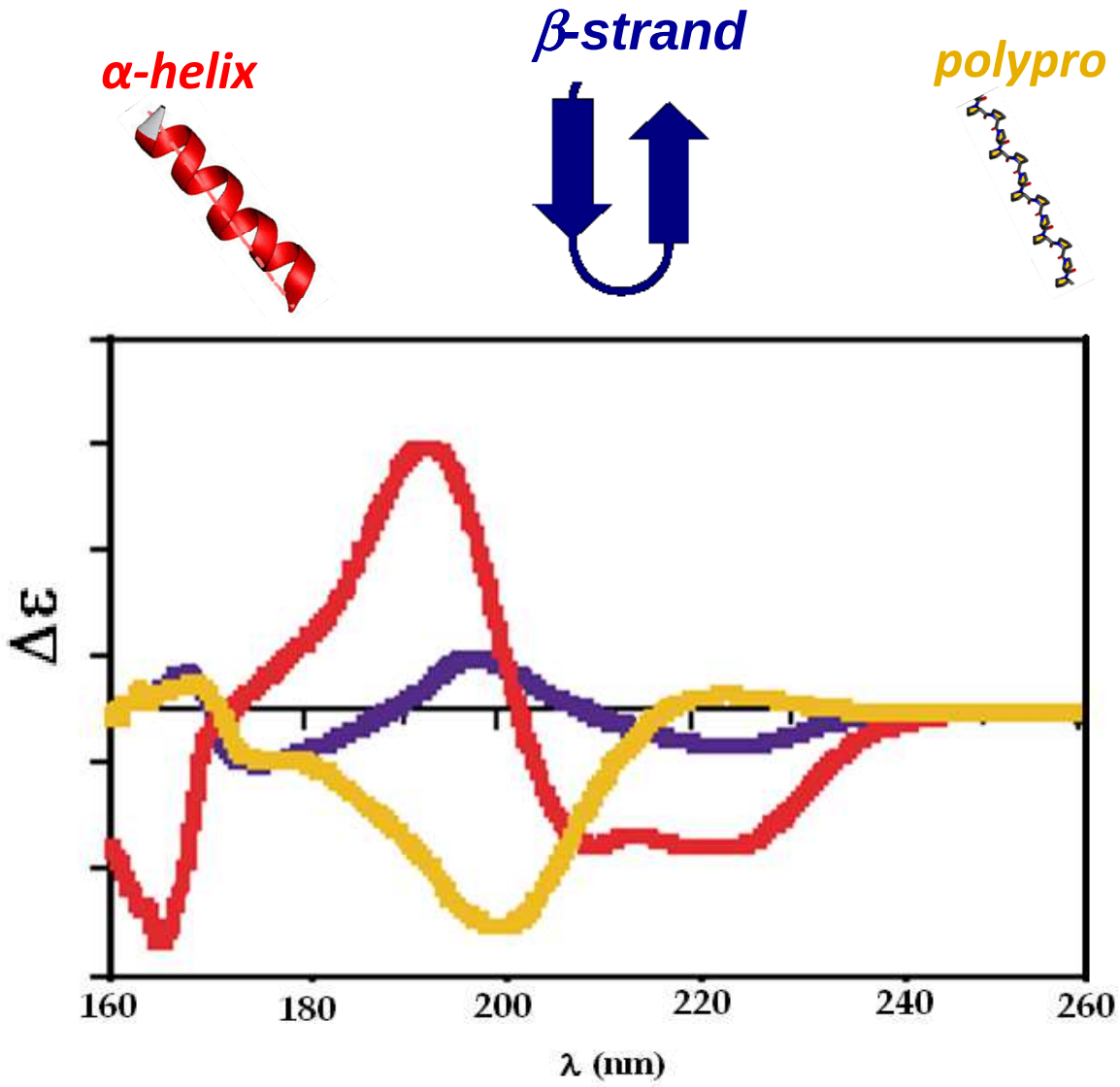


Chromophore	Example	Excitation	λ_{max}, nm
C=C	Ethene	$\pi \rightarrow \pi^*$	171
C≡C	1-Hexyne	$\pi \rightarrow \pi^*$	180
C=O	Ethanal	$n \rightarrow \pi^*$ $\pi \rightarrow \pi^*$	290 180
N=O	Nitromethane	$n \rightarrow \pi^*$ $\pi \rightarrow \pi^*$	275 200
C-X X=Br X=I	Methyl bromide Methyl Iodide	$n \rightarrow \sigma^*$ $n \rightarrow \sigma^*$	205 255

Dicroísmo Circular (CD)

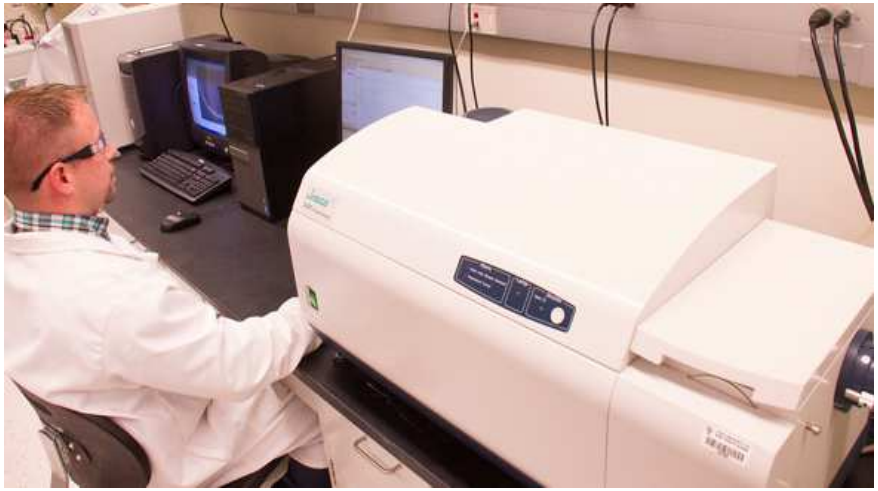


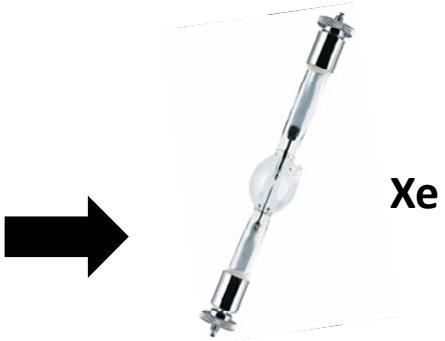
Estrutura Secundária de Proteínas

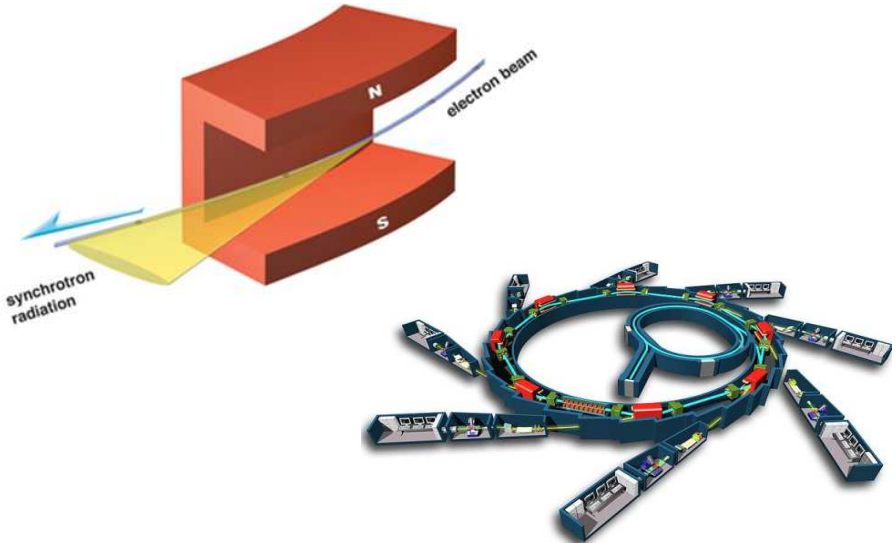


Wallace & Janes, Curr Opin Chemical Biol 5:567-71 (2001)

CD

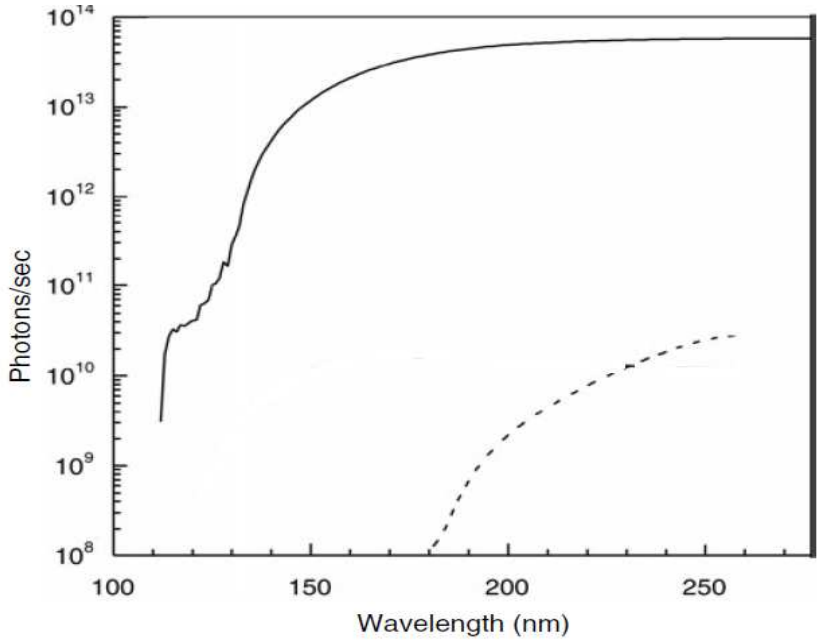


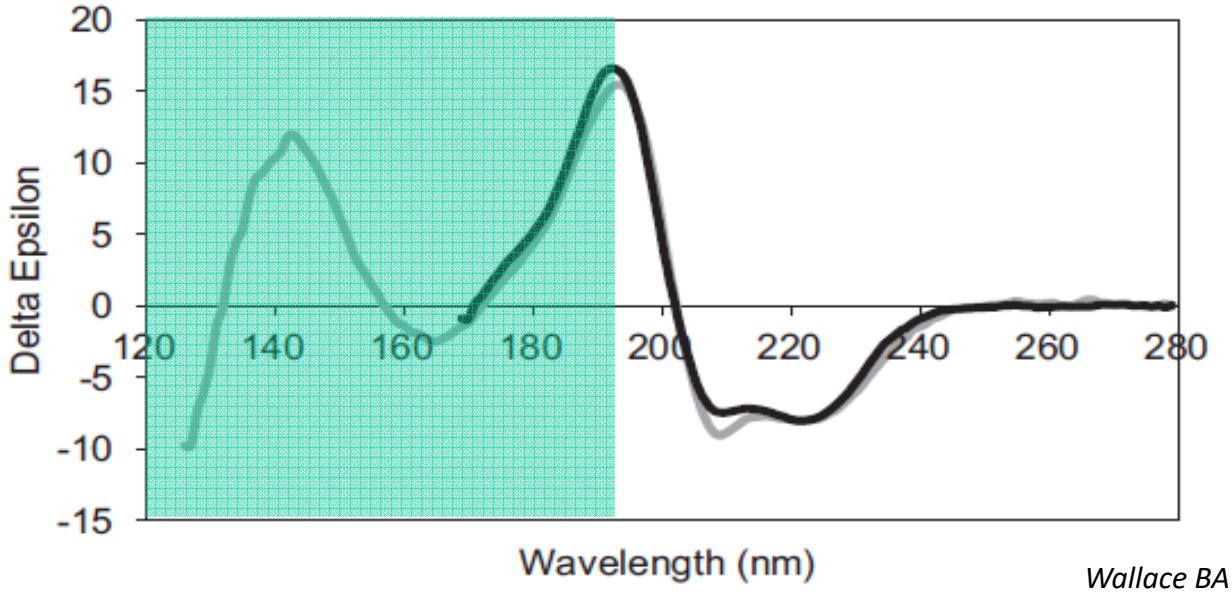




UV-CD12, ANKA, Karlsruhe, Germany

Radiação Síncrotron *vs* Xe Arc Lamp

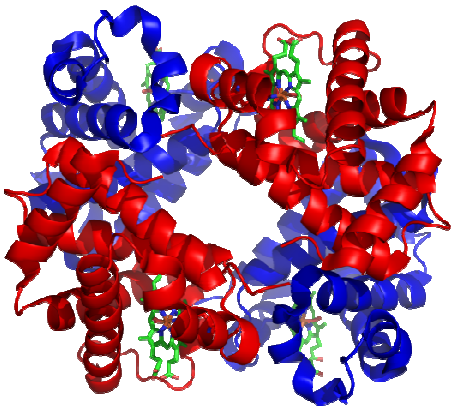


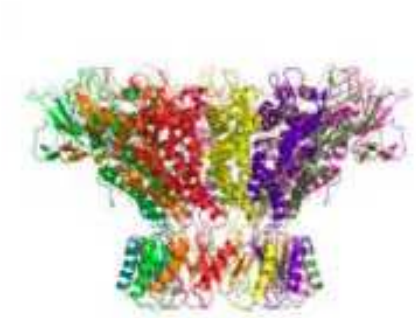


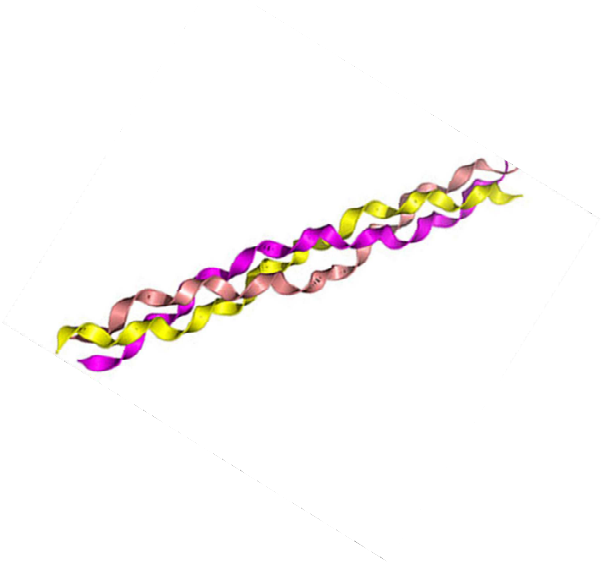
Wallace BA QRB 42: 317-70 (2009)

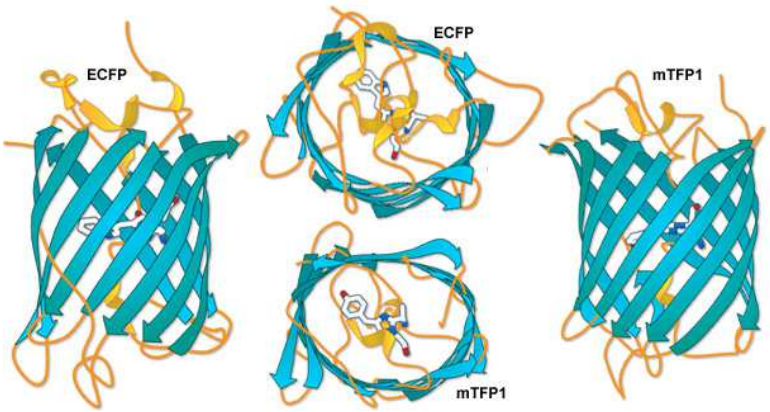
Porque é importante conhecer a estrutura de proteínas?

Diversidade Estrutural

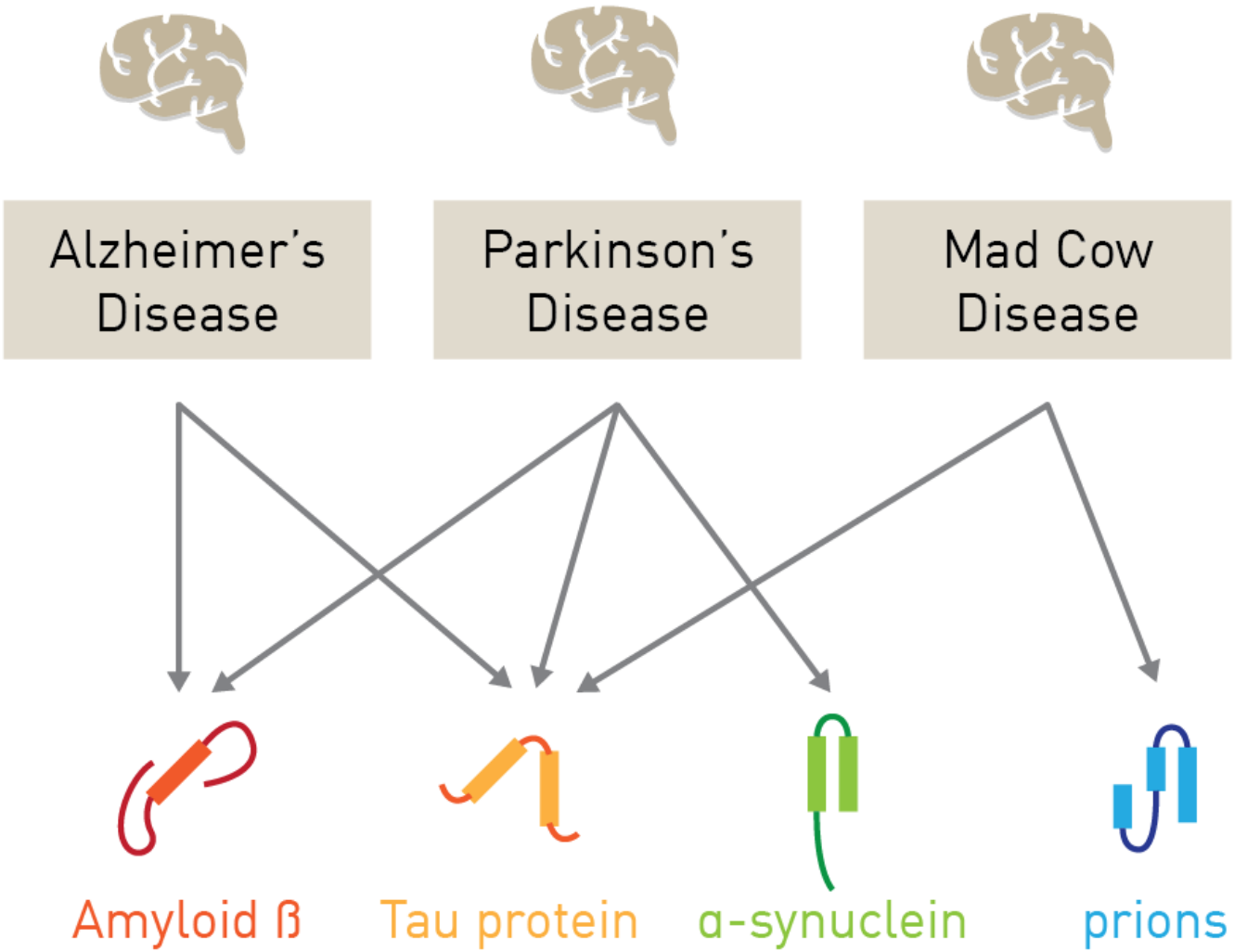




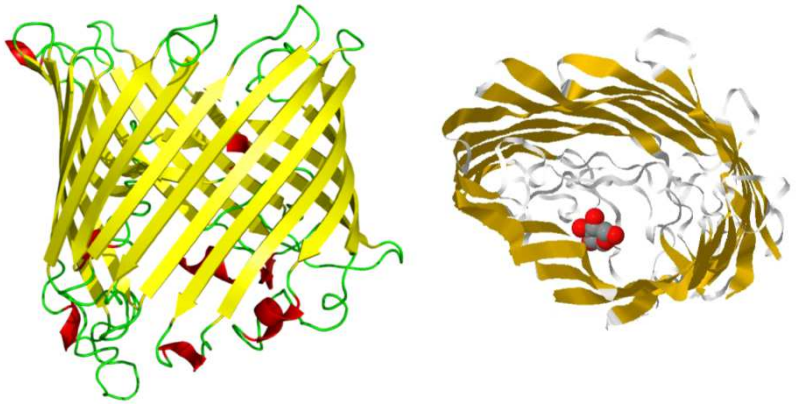


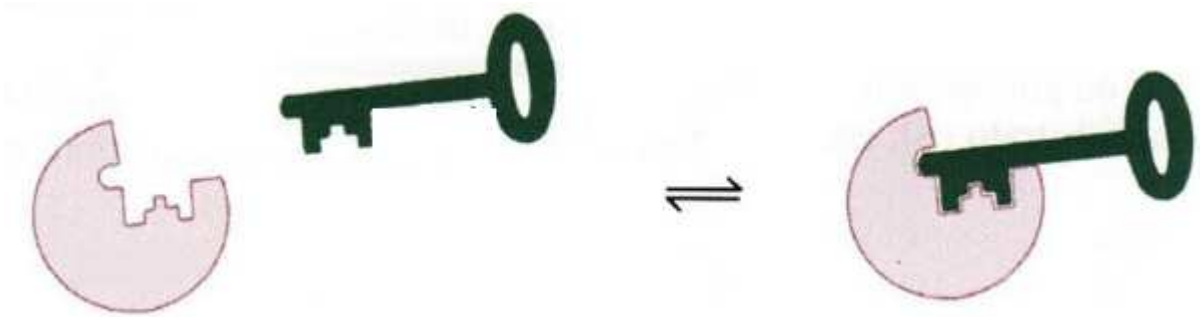


Proteínas mal enoveladas



Paradigma Estrutura-Função





Proteínas intrinsicamente desordenadas (IDPs)

IDPs

Who

Outros nomes

flexible

vulnerable

malleable

pliable

floppy

rheomorphic

mobile

chameleon

natively unfolded

partially folded

natively denatured

natively disordered

intrinsically denatured

intrinsically unfolded

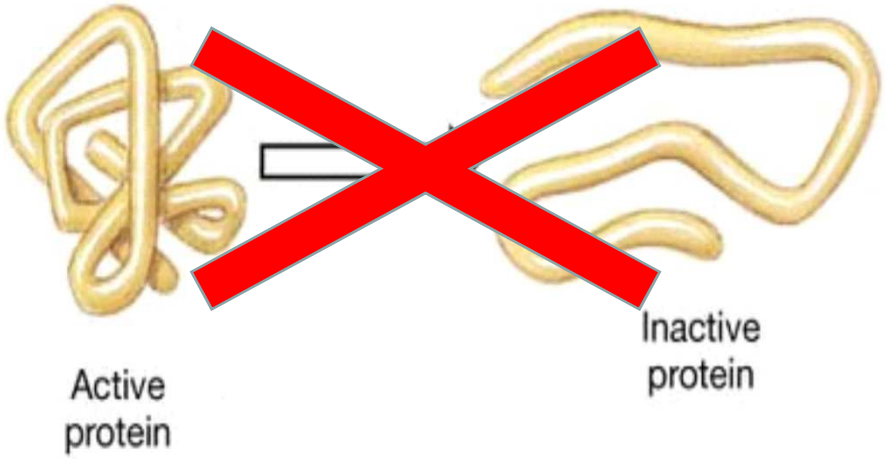
intrinsically unstructured

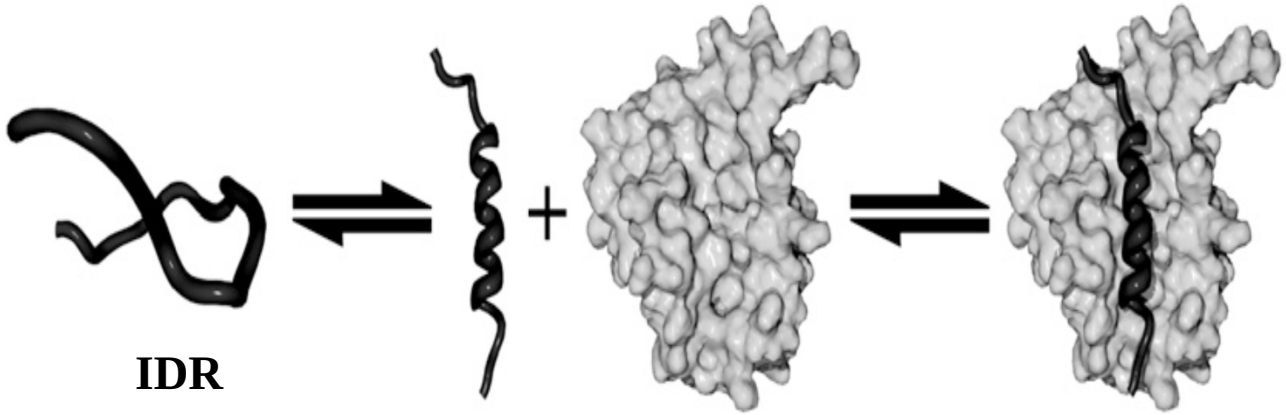
dancing proteins

protein clouds

Who

IDPs

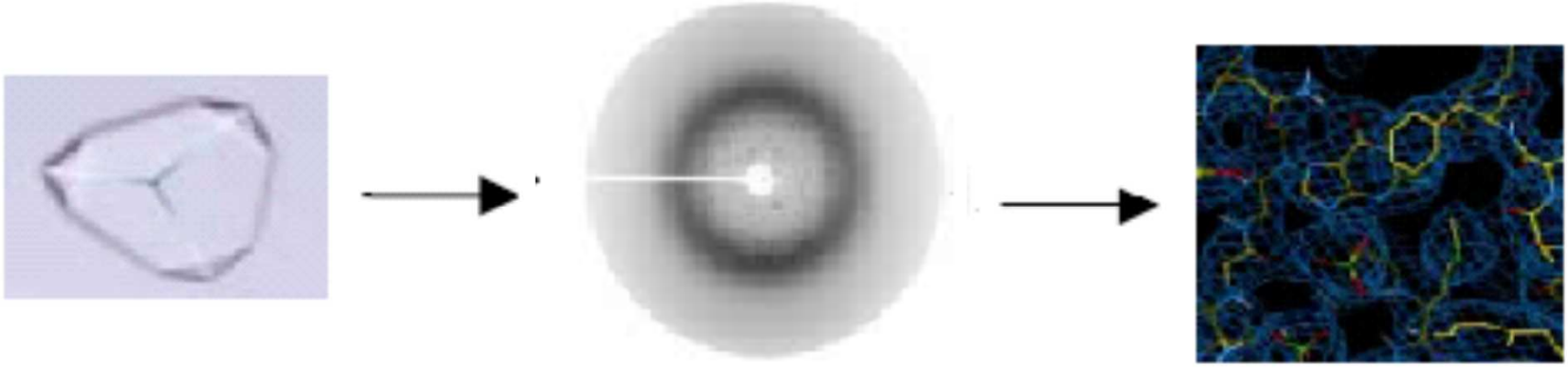




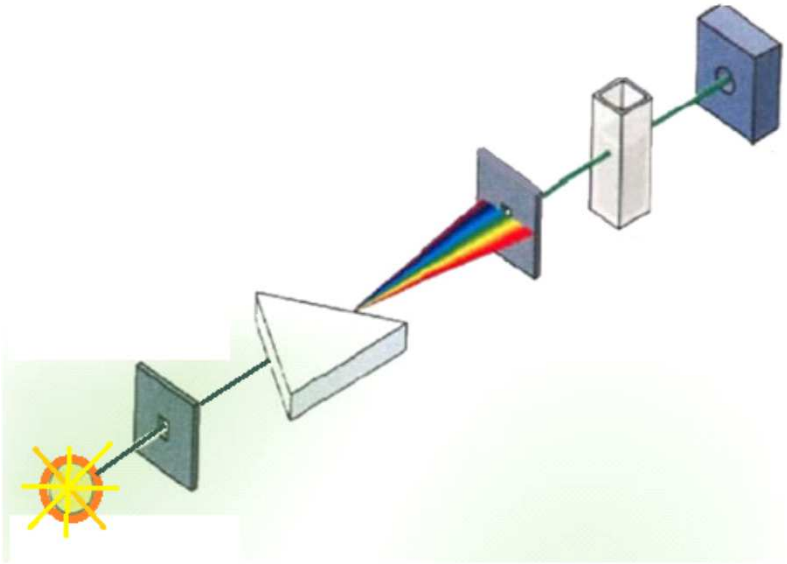
Radijovac, et al. 2007. Byophisical Journal, 92.

What

Estudo estrutural de proteínas



versus



How

Por que desordenadas?

Carga

Hidrofobicidade

Conteúdo de Prolina

Propensão de Estrutura Secundária

Funções das IDPs

50% proteínas em mamíferos

70% proteínas sinalizadoras

Realizam múltiplas interações

Funções das IDPs

Interação

Ácidos nucleicos **Íons Metálicos**

…IDPs are likely to be rich sources of unforeseen activities

Endonuclease **Chaperon-like**

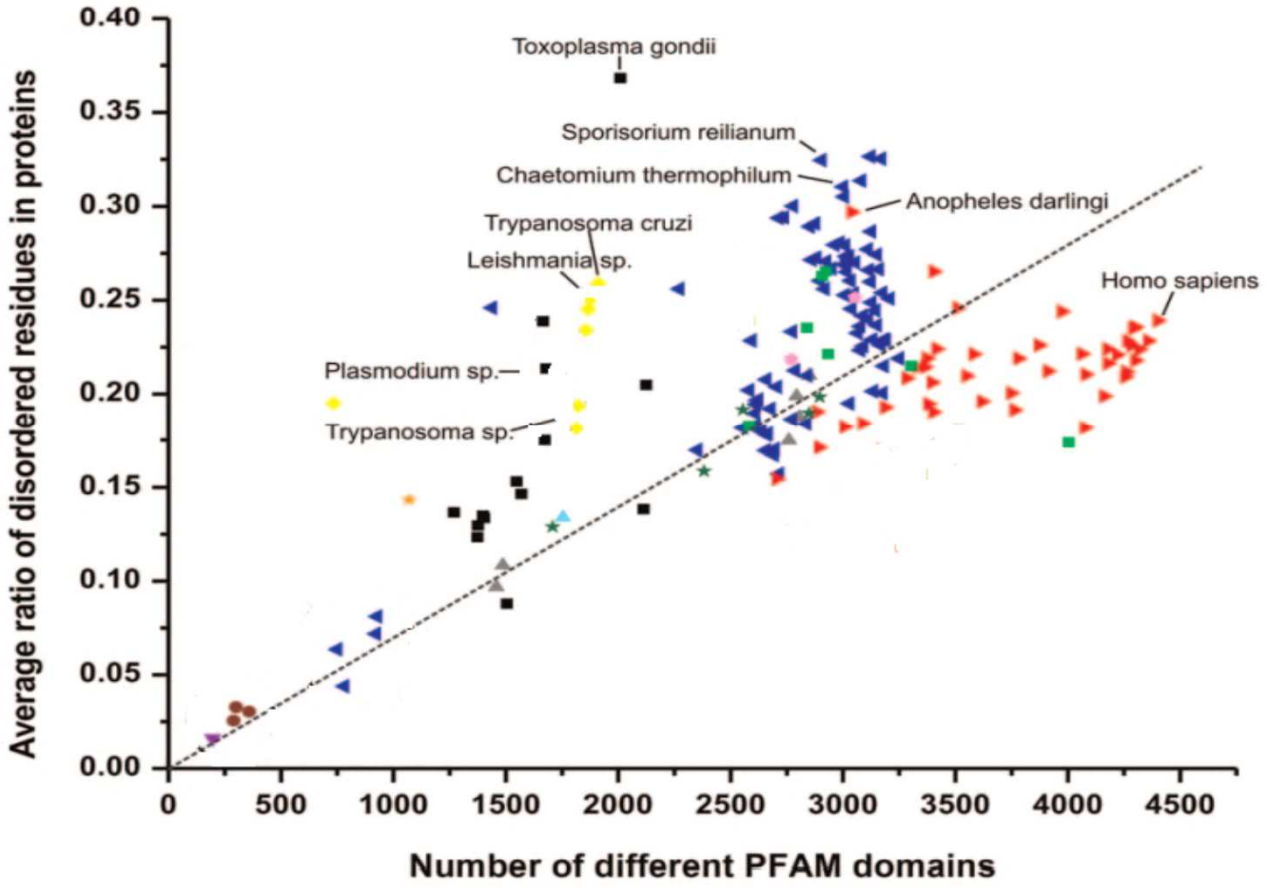
Where

Era uma vez...

Exemplo

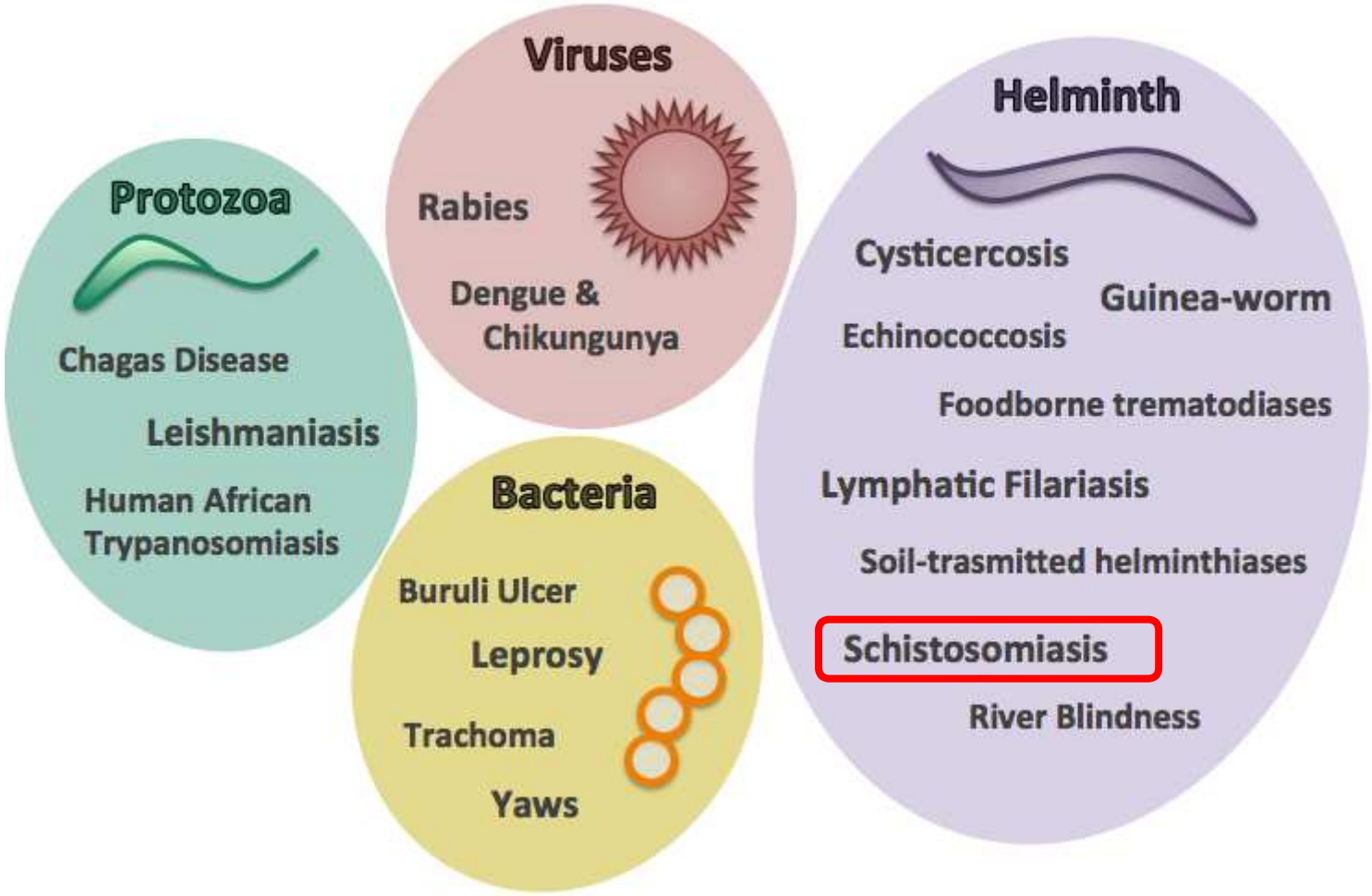
MEG-14

Desordem nas proteínas

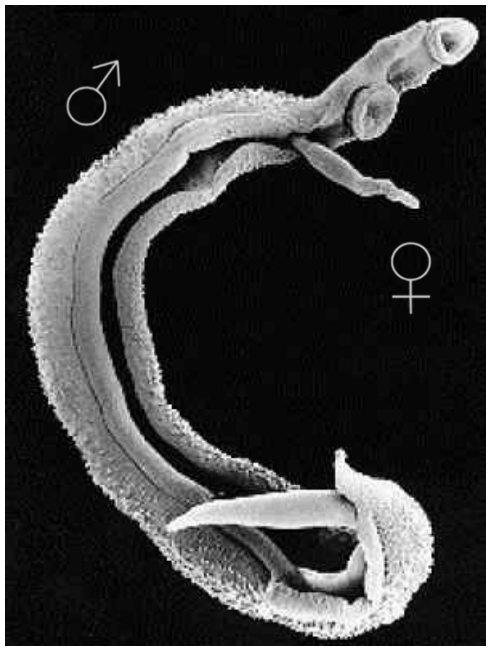


Pancsa & Tompa. PloS, 2012

Parasitas


Viruses
Rabies
Dengue &
Chikungunya
Protozoa
Chagas Disease
Leishmaniasis
Human African
Trypanosomiasis
Helminth
Cysticercosis
Guinea-worm
Echinococcosis
Foodborne trematodiases
Lymphatic Filariasis
Soil-trasmitted helminthiases
Schistosomiasis
River Blindness
Bacteria
Buruli Ulcer
Leprosy
Trachoma
Yaws

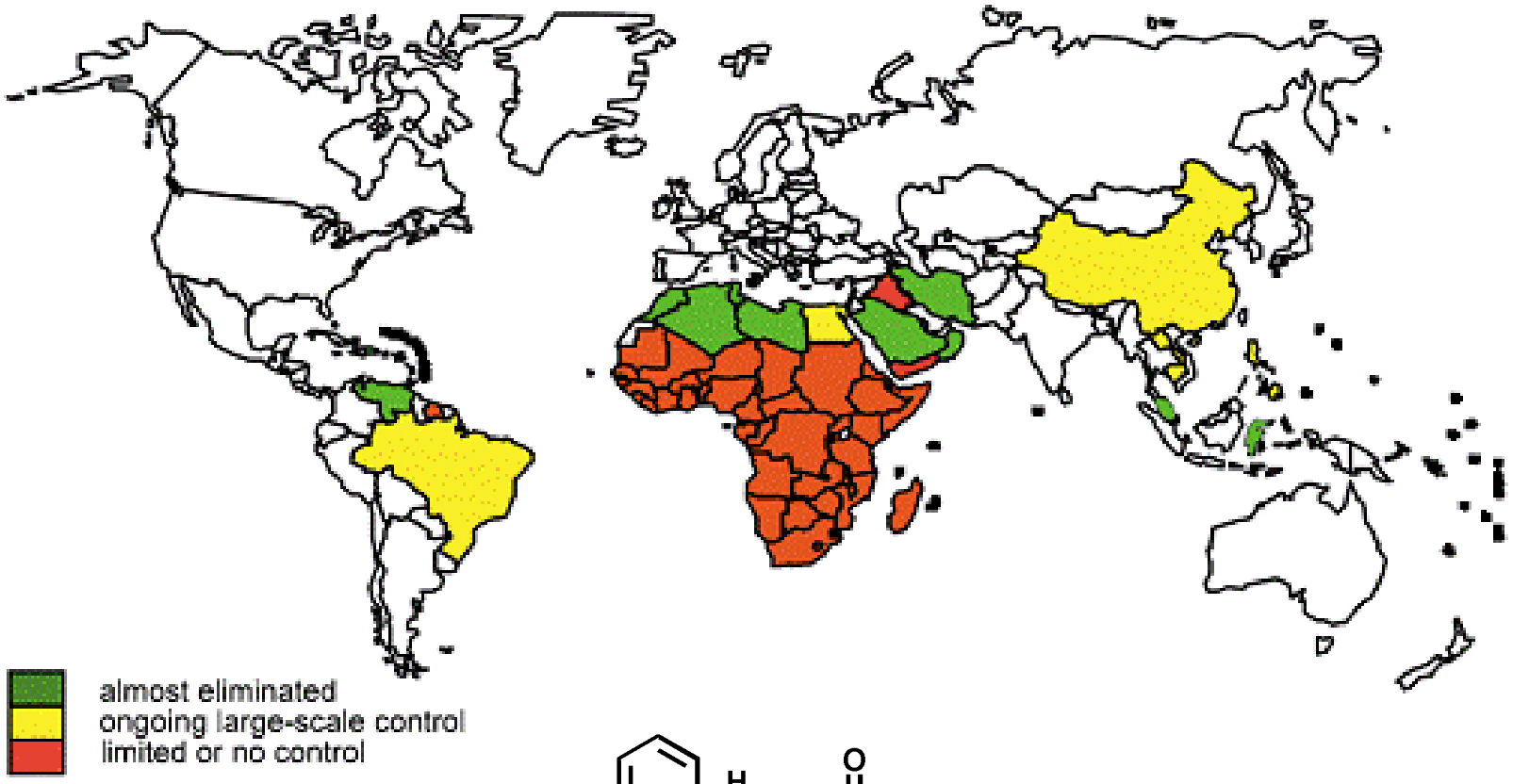
Schistosoma mansoni

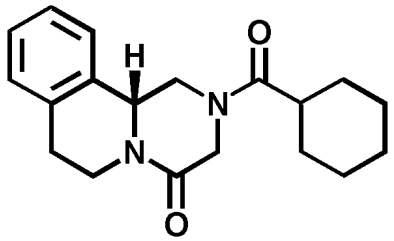


	Infected	*Death/year*
Schistosomiasis	**240 million**	**322 thousand**
Malaria	**283 million**	**755 thousand**

WHO, Dec.2015

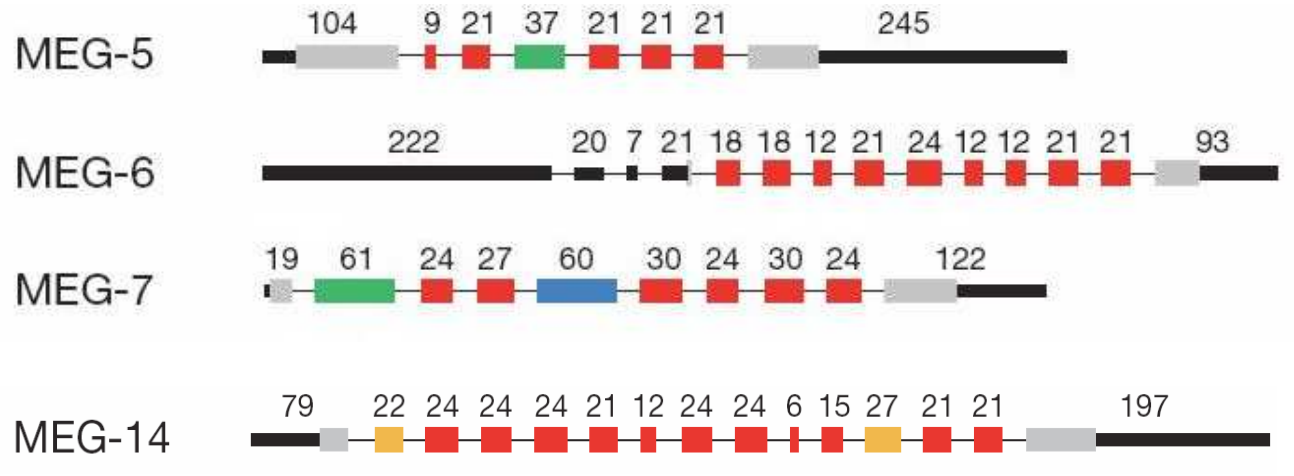
Schistosomiasis World Map





1, Praziquantel (PZQ)

Micro-Exon Genes

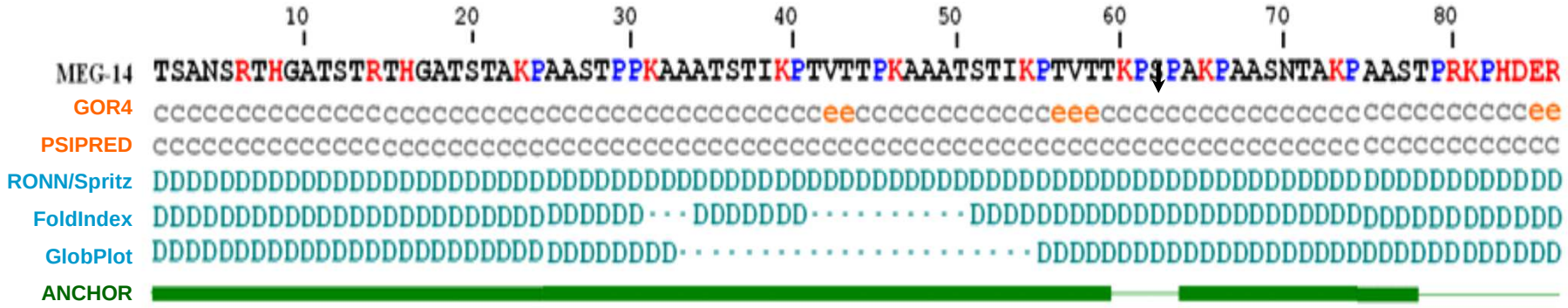


Berriman M, et al. Nature 460 352-8, 2009

MEG-14

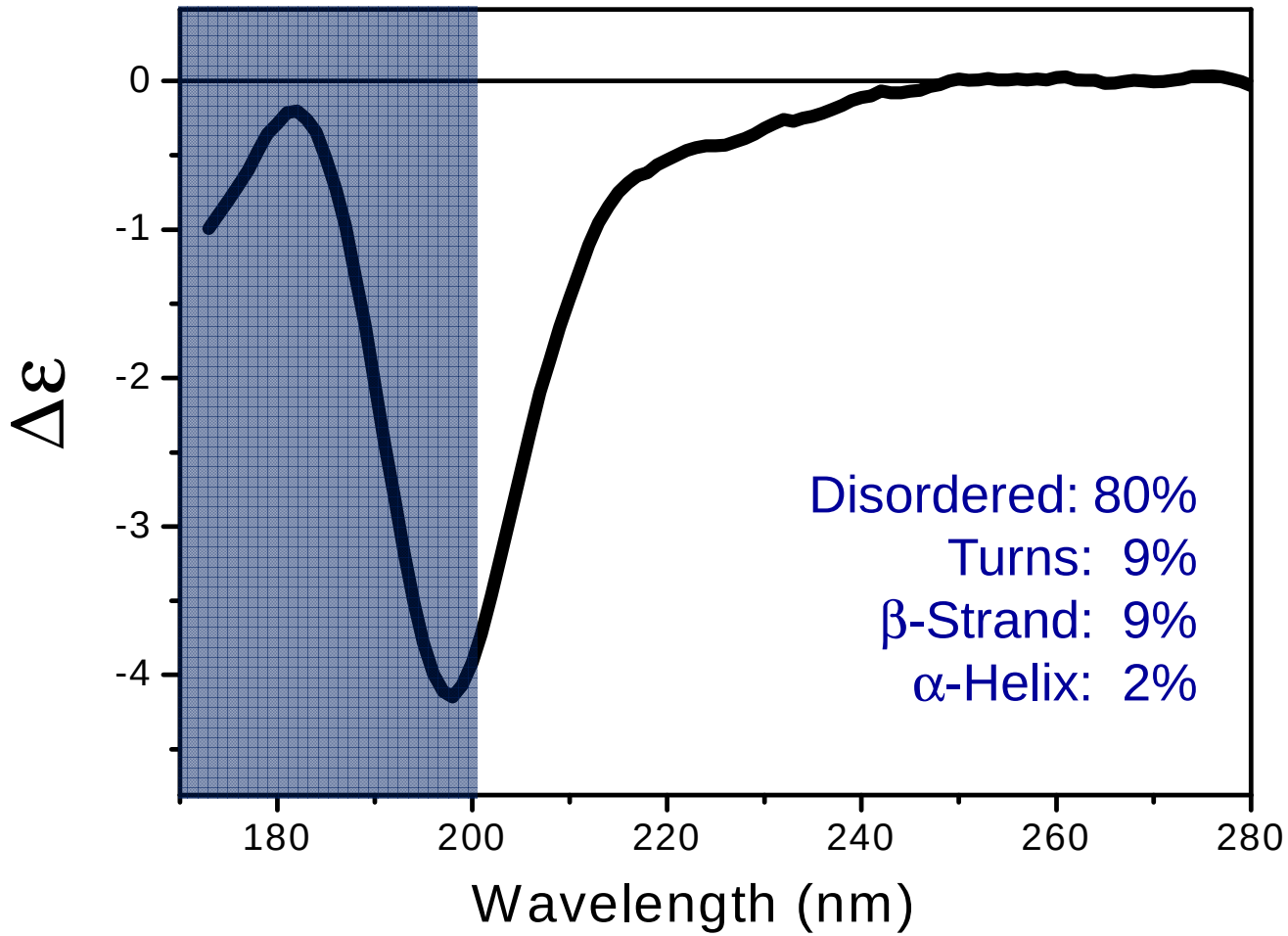
```
          10                  20                  30
TSANSRTHGA TSTSTHGATS TAKPAASTPP

          40                  50                  60
KAAATSTIKP TVTTPKAAAT STTEPTVTTK

          70                  80
PSPAKPAASN TAKPAASTPK KPHDER
```

Análises de Bioinformática

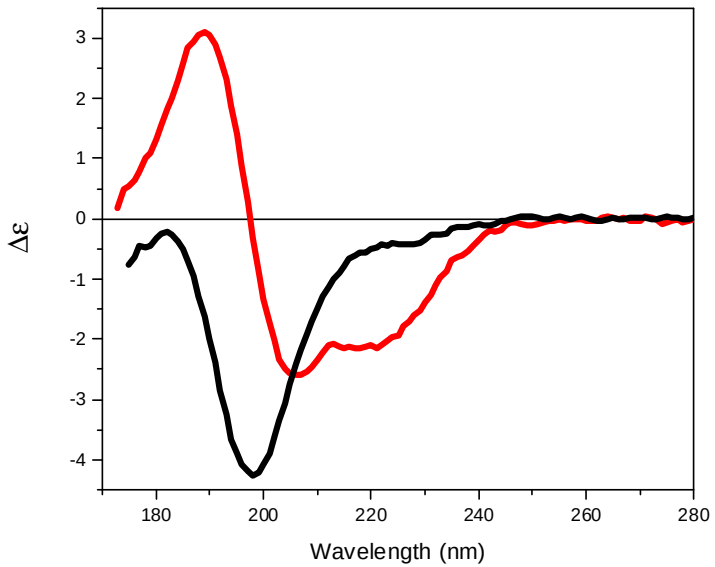


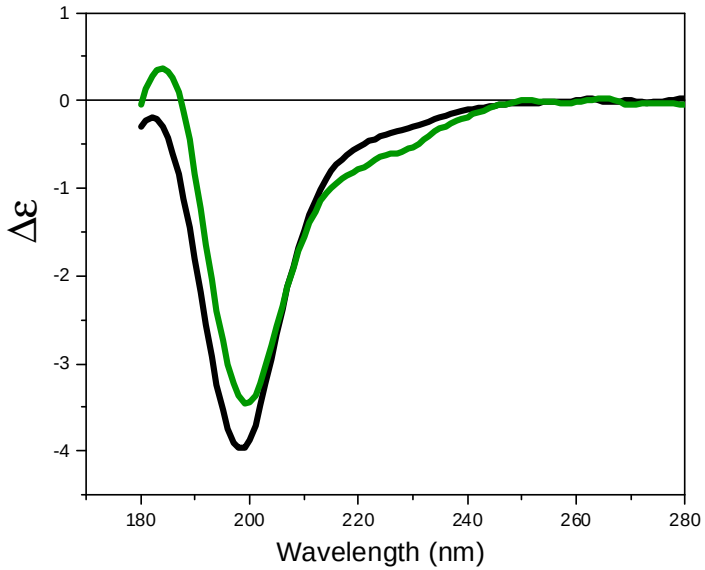
Lopes JLS, et al. 2013. Biophys. J. 104

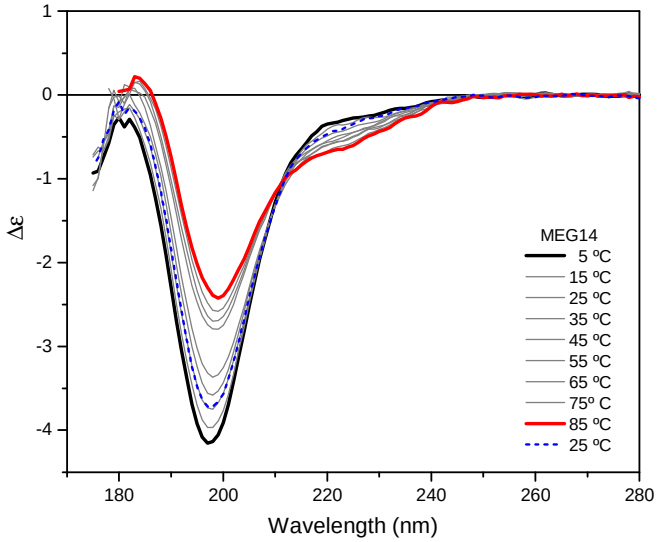
SRCD

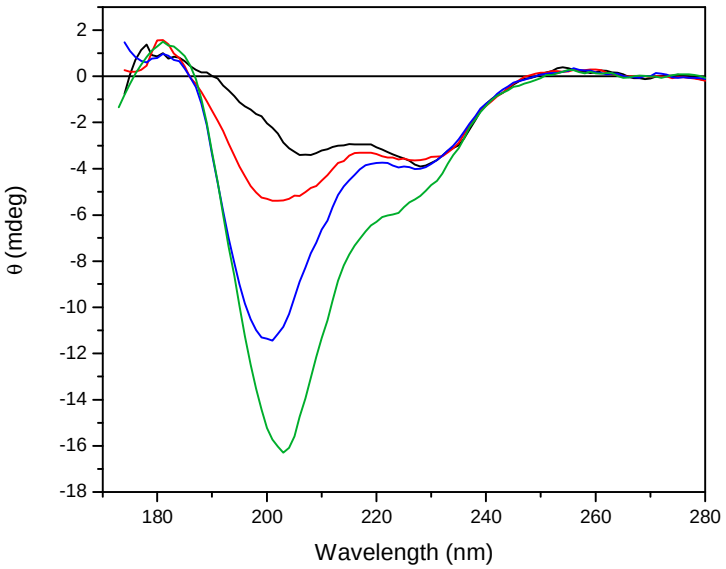

0
-1
-2
-3
-4
Δε
180
200
220
240
260
280
Wavelength (nm)
Disordered: 80%
Turns: 9%
β-Strand: 9%
α-Helix: 2%

SRCD

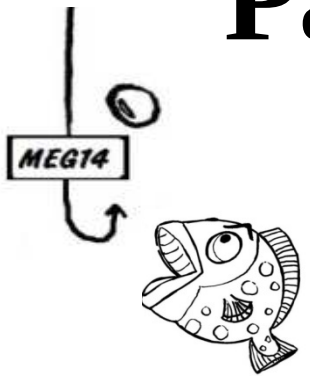

Δε
Wavelength (nm)


Δε
Wavelength (nm)


Δε
Wavelength (nm)
MEG14
5 ºC
15 ºC
25 ºC
35 ºC
45 ºC
55 ºC
65 ºC
75º C
85 ºC
25 ºC


θ (mdeg)
Wavelength (nm)

Parceiros para MEG-14

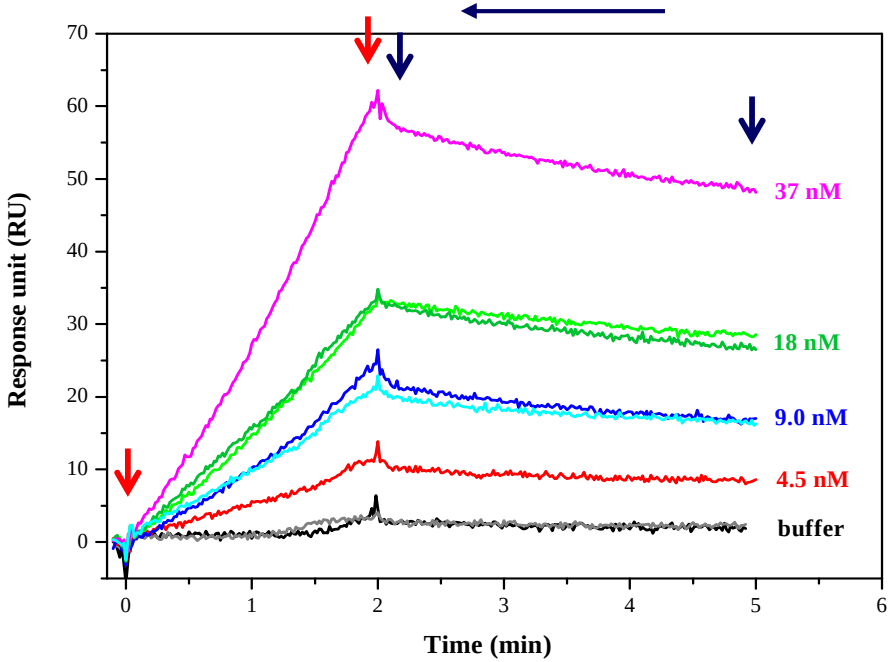


Yeast two hybrid system

Pull Down Assays

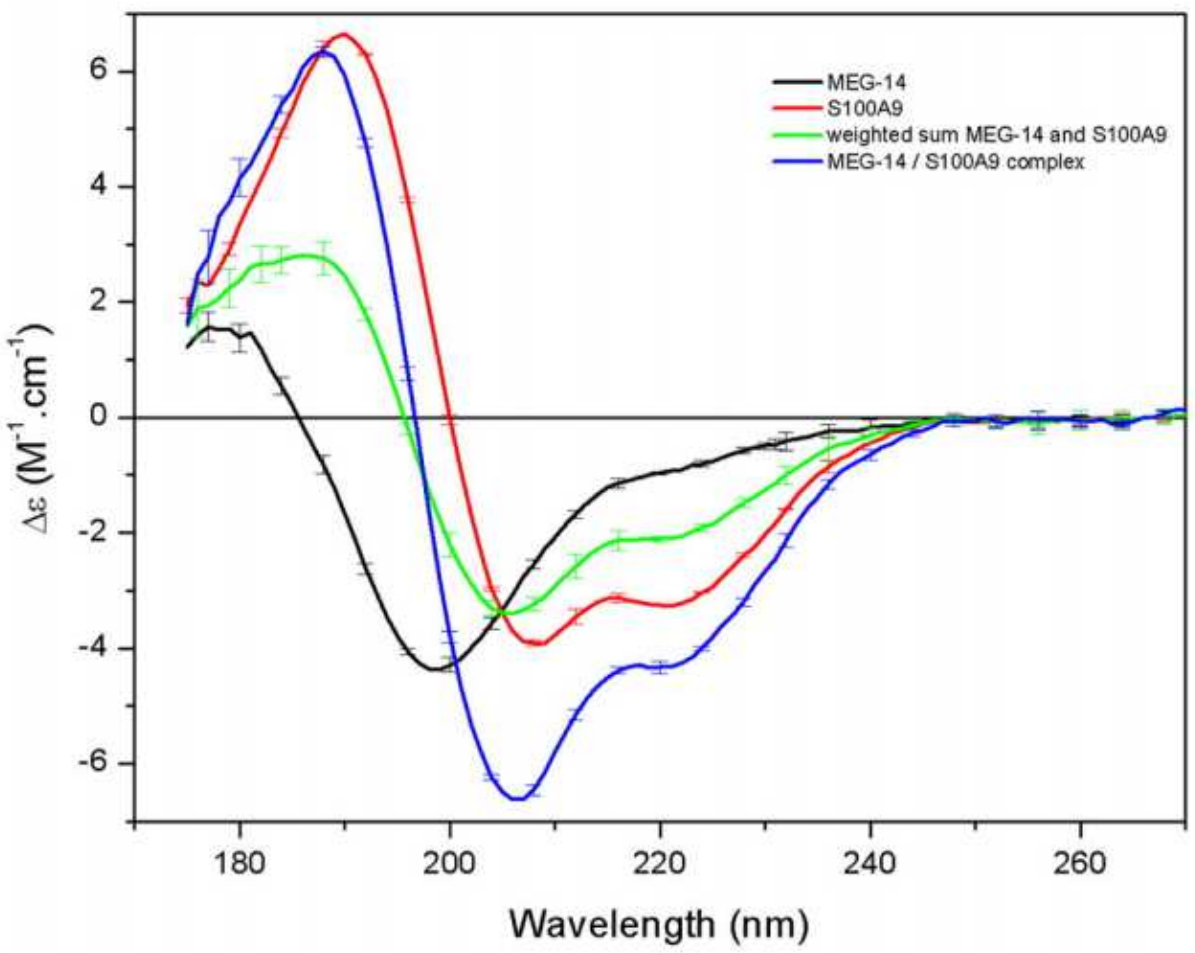
S100A9

$M_{EG14} + S_{100A9} \rightleftharpoons MS_{complex}$



K_D = 1.8 µM

Parceiro para MEG-14



MEG-14 é um membro do grupo das IDPs

Possibilidade de interagir com diferentes parceiros no hospedeiro e assumer diferentes papéis

MEG-14 é um membro do grupo das IDPs

MEG-14 pode ser parcialmente enovelada

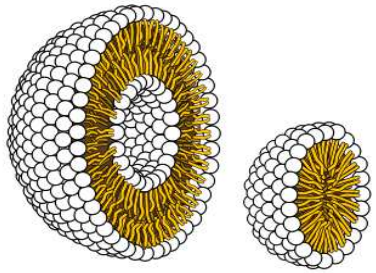
S100A9 deve ser um parceiro para MEG-14

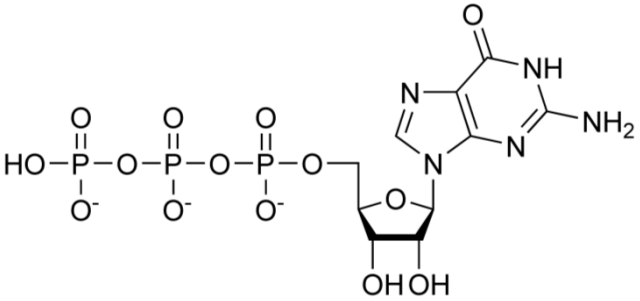
Disorder-to-order transitions are observed on a IDPs when interacting with partners

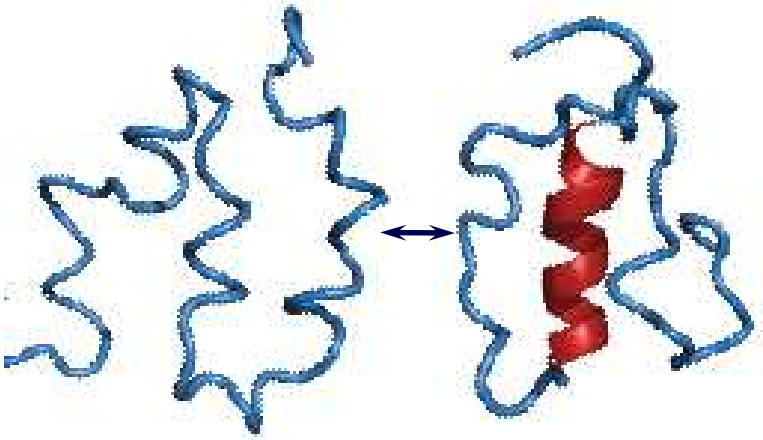
IDPs can adopt different conformations

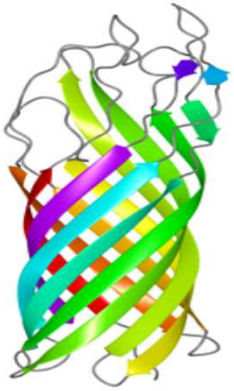
CD and SRCD are useful techniques for studying IDPs

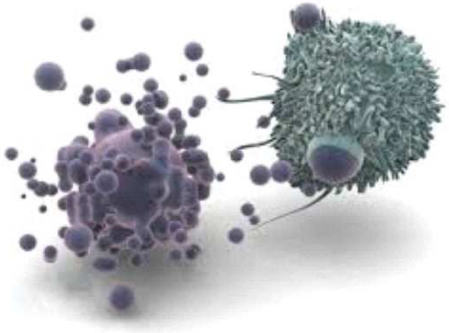
SRCD provides additional bands for analysing the disordered state

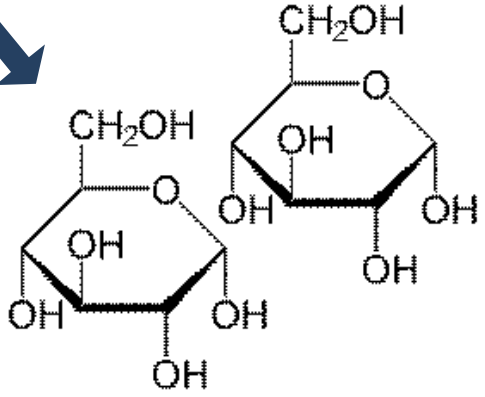



O
NH
N
NH2
N
N
HO
P
O
O-
OH OH








CH2OH
O
OH
OH
OH
CH2OH
O
OH
OH
OH
OH

Acknowledgments

Collaborators

Prof. Dr. B.A. Wallace, Birkbeck College, UK

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