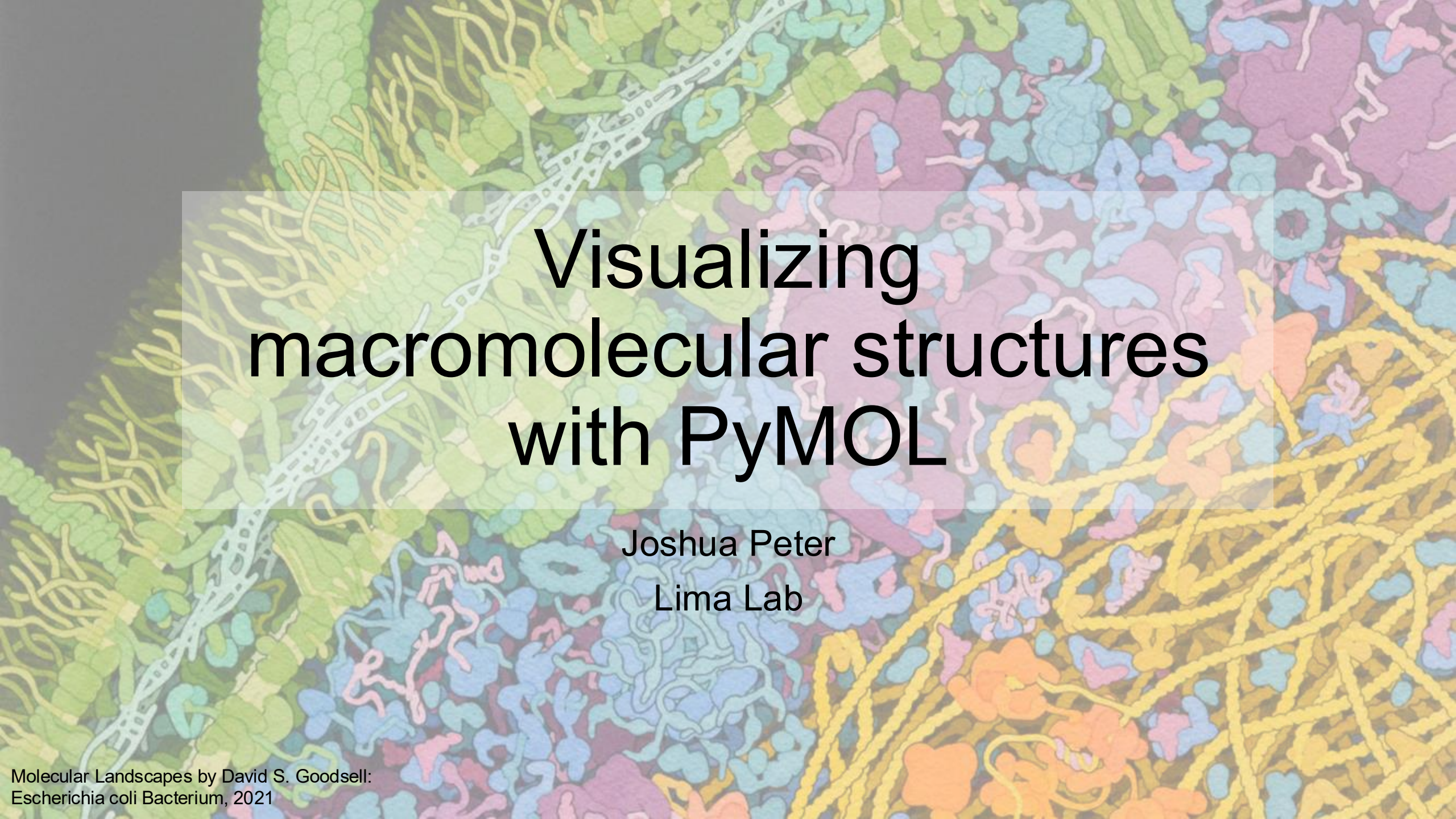




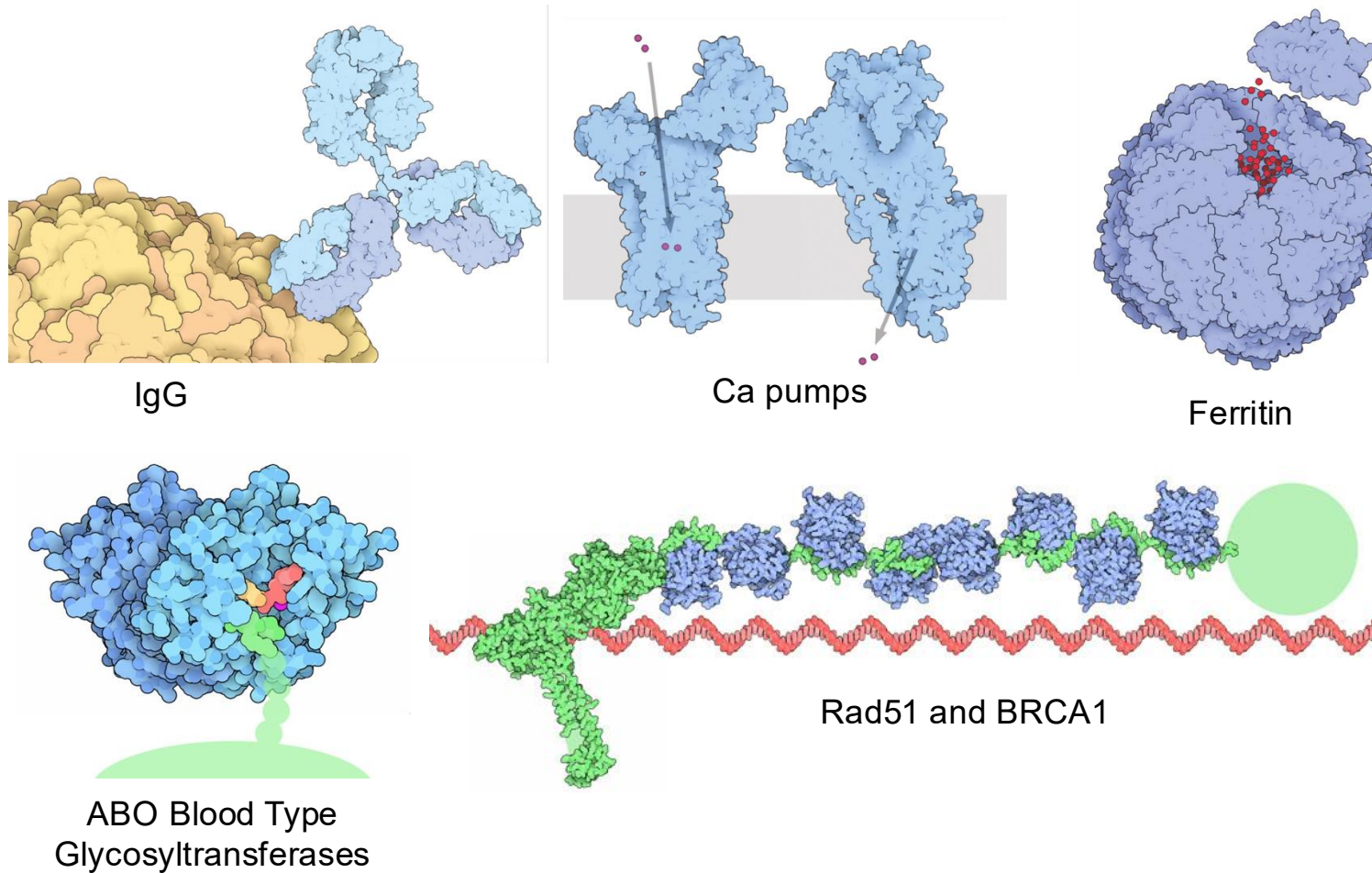
Visualizing macromolecular structures with PyMOL

Joshua Peter
Lima Lab

Structure informs function of proteins

How Do DRUGS Work? Examples from the PDB archive

PROTEINS are tiny molecular machines that perform most of the tasks needed to keep cells alive. These machines are far too small to see, so you might imagine that it is impossible to affect their action. However, drugs can be used to turn proteins on or off. DRUGS are small molecules that bind to proteins and modify their actions. Some very powerful drugs, such as antibiotics or anticancer drugs, are used to completely disable a critical molecular machine. These drugs can kill a bacterial or cancer cell. Other molecules, such as aspirin, gently block less-critical proteins for a few hours. With the use of these drugs, we can make changes inside our own cells, such as the blocking of pain signals. Many structures of drugs that bind to proteins have been determined by scientists. These atomic structures allow us to see how drugs work, and perhaps how to modify them to improve their action. A few examples are shown here. Some of these drugs, like penicillin, were discovered in nature. Other drugs, such as HIV protease inhibitors, were created by using the target protein structure to design new drug molecules. These structures of proteins and drugs, along with many others, can be explored at the RCSB Protein Data Bank (PDB).



Antibiotics & Antivirals

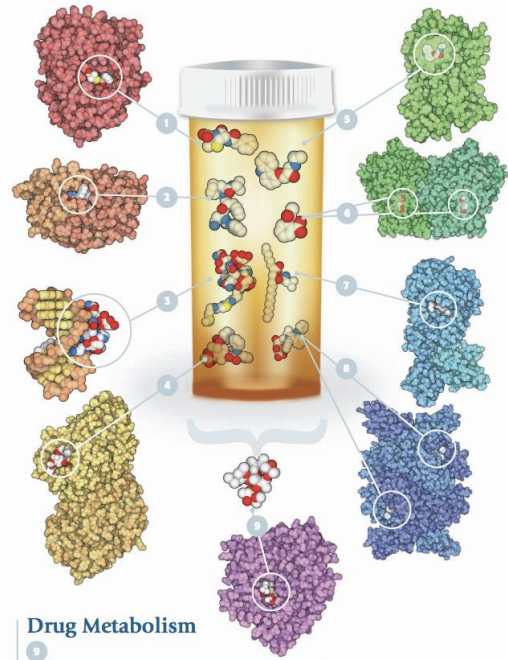
Antibiotics and antiviral drugs are specific poisons. They need to kill pathogenic organisms like bacteria and viruses without poisoning the patient at the same time. Often, these drugs attack proteins that are only found in the targeted bacterium or virus and which are crucial for their survival or multiplication. For instance, penicillin attacks the enzyme that builds bacterial cell walls, and HIV protease inhibitors like saquinavir attack an enzyme that is needed for HIV maturation.

1. D-alanyl-D-alanine carboxypeptidase with penicillin (1pnc)
2. HIV protease with saquinavir (1hsb)

Anticancer Chemotherapy

Cancer cells grow and multiply without control. Since these cells are still similar to normal cells, it is difficult to kill them selectively with drugs that can't distinguish between the two. Many drugs currently used for cancer chemotherapy attack all growing cells, including cancer cells and normal cells. This causes the severe side effects of cancer chemotherapy, because the drugs attack rapidly-growing cells in hair follicles and the stomach. Two examples are shown here. Bleomycin attacks DNA in actively growing cells, often cleaving the DNA chain and killing the cell. Paclitaxel (taxol) binds to tubulin, preventing the action of microtubules during cell division.

3. DNA with bleomycin (1msk)
4. Tubulin with taxol (1pfr)



Drug Metabolism

You have probably noticed that when you take drugs, the effects gradually wear off in a few hours. Enzymes like cytochrome P450 continually search for drugs and destroy them. This is important because it protects us from poisonous molecules in our diet and in the environment, but it means that we have to take multiple doses of drugs when being treated for a disease.

5. Cytochrome P450 3A4 with erythromycin (2jhe)

Drugs of Signaling Proteins

Many drugs are designed to keep bodily processes at normal healthy levels. Much of the body's regulation is done through elaborate communications between cells, so some of the most widely prescribed drugs function by blocking the signaling proteins that allow cells to communicate. G protein-coupled receptors, which transmit signals across cell membranes, are targets for many drugs. For instance, the drug lorazepam (Claritin) is used to treat allergies because it blocks the histamine receptor; losartan (Cozaar) is used to treat high blood pressure because it blocks the angiotensin II receptor; and carazolol is one of a large class of beta-blockers that bind to the adrenergic receptor, making it useful for treating heart disease. Signals can also be stopped by blocking the enzymes that create a signaling molecule. Aspirin blocks pain at the source by inhibiting the enzyme cyclooxygenase, which makes pain-signaling prostaglandin molecules.

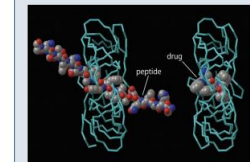
6. Prostaglandin H2 synthase with aspirin (1phs). The drug breaks into two pieces when it binds to the enzyme, and the smaller piece (an acetyl group) is attached to the enzyme with a covalent bond. The closeup shows the drug in one piece.

Lifestyle Drugs

Pharmaceutical scientists have developed a number of drugs that help people modify their own health and bodily function. The drug orlistat (Xenical or alli) blocks the action of pancreatic lipase, and thereby reduces the amount of fat that is absorbed from food. Atorvastatin (Lipitor) and simvastatin (Zocor) lower cholesterol by blocking the action of HMG-CoA reductase, an enzyme involved in the synthesis of cholesterol. These drugs can be used, along with changes in diet and exercise, to help lose weight, regulate cholesterol levels, and control heart disease.

7. Pancreatic lipase with an allyl phosphonate inhibitor (1lps). The drug orlistat shown on the right is similar to the inhibitor found in the crystal structure.
8. HMG-CoA reductase with atorvastatin (1hsk)

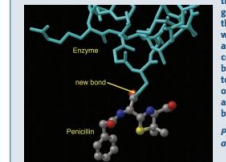
Molecular Mimics



Most drugs mimic the molecules that are normally processed by an enzyme or receptor protein. They bind tightly to the protein and block the site that usually performs the task. For instance, HIV protease normally binds to a protein chain, like the one shown at the left, and clips it into two pieces. Drugs used to treat HIV infection, like saquinavir shown here, are smaller than the protein chain but chemically very similar. The drug binds in a similar position as the peptide, completely blocking the active site so the enzyme is unable to cleave the protein chain. (Image created with the Python Molecular Viewer—mgtools.scripps.edu)

Peptide bound (2nsd) and drug bound (1hsb) structures of HIV protease.

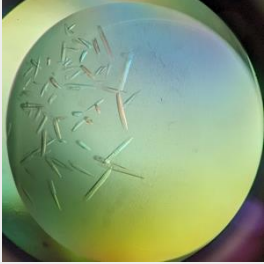
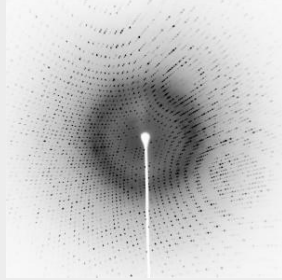
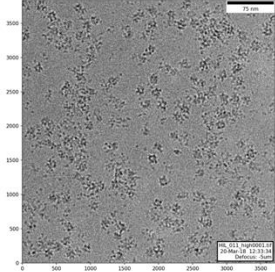
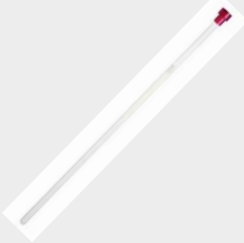
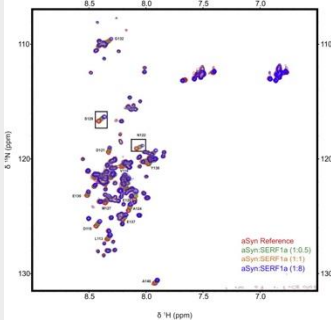
Suicide Inhibitors



Some drugs are particularly effective because they form a chemical bond to the protein target (shown in turquoise), totally disabling it in the process. Penicillin (shown at the bottom with atomic colors) reacts with a serine amino acid in the bacterial enzyme, forming a new covalent bond to the enzyme. This completely blocks the active site, so the enzyme is unable to perform its role in cell wall synthesis. Another suicide inhibitor, aspirin (shown in #6), attaches an acetyl group to its target which blocks an inflammation pathway.

Penicillin bound structure of D-alanyl-D-alanine carboxypeptidase (PDB entry 1pnc)

How do we determine protein structures?

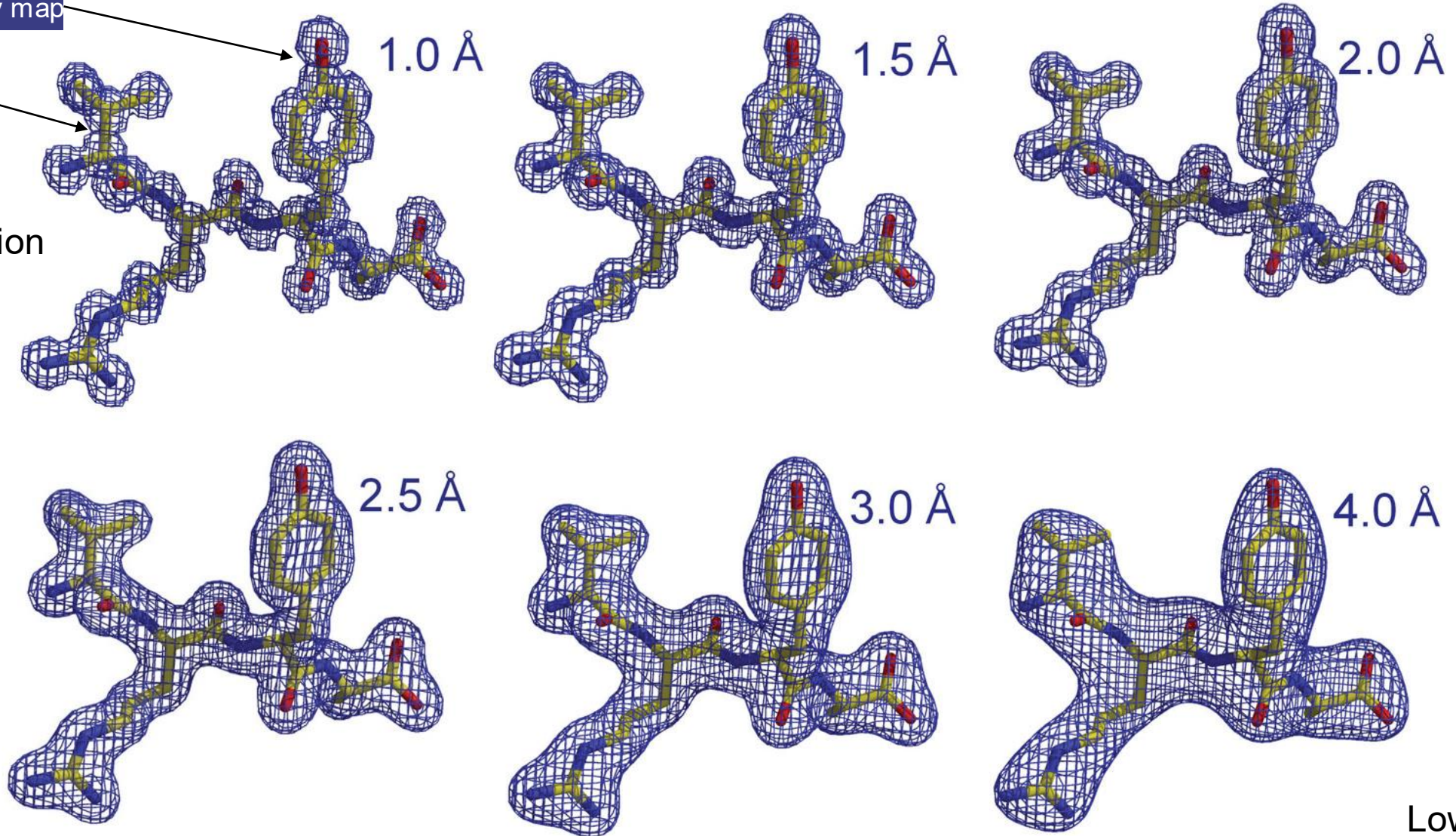
Method	Sample	Instrument	Data	Advantages	Limitations
X-ray crystallography	Crystals 	Synchrotron 	Diffraction pattern 	- High-res data - Very common - No size restriction	- Dependent on crystallization - Limited conformations
Cryo-electron microscopy	Sample vitrified on grids 	Electron microscope 	Micrographs 	- Can capture states - Small amount of sample required - Fast sample prep	- Size limit (smaller = harder) - Preferred orientation - Computationally intensive
Nuclear Magnetic Resonance Spectroscopy	Sample in solvent 	NMR Spectrometer 	NMR spectra 	Only method for real-time, in-solution motion detection	- Size limit (larger = harder) - Need a lot of very pure sample

Resolution and information level

Electron density map

Atomic model

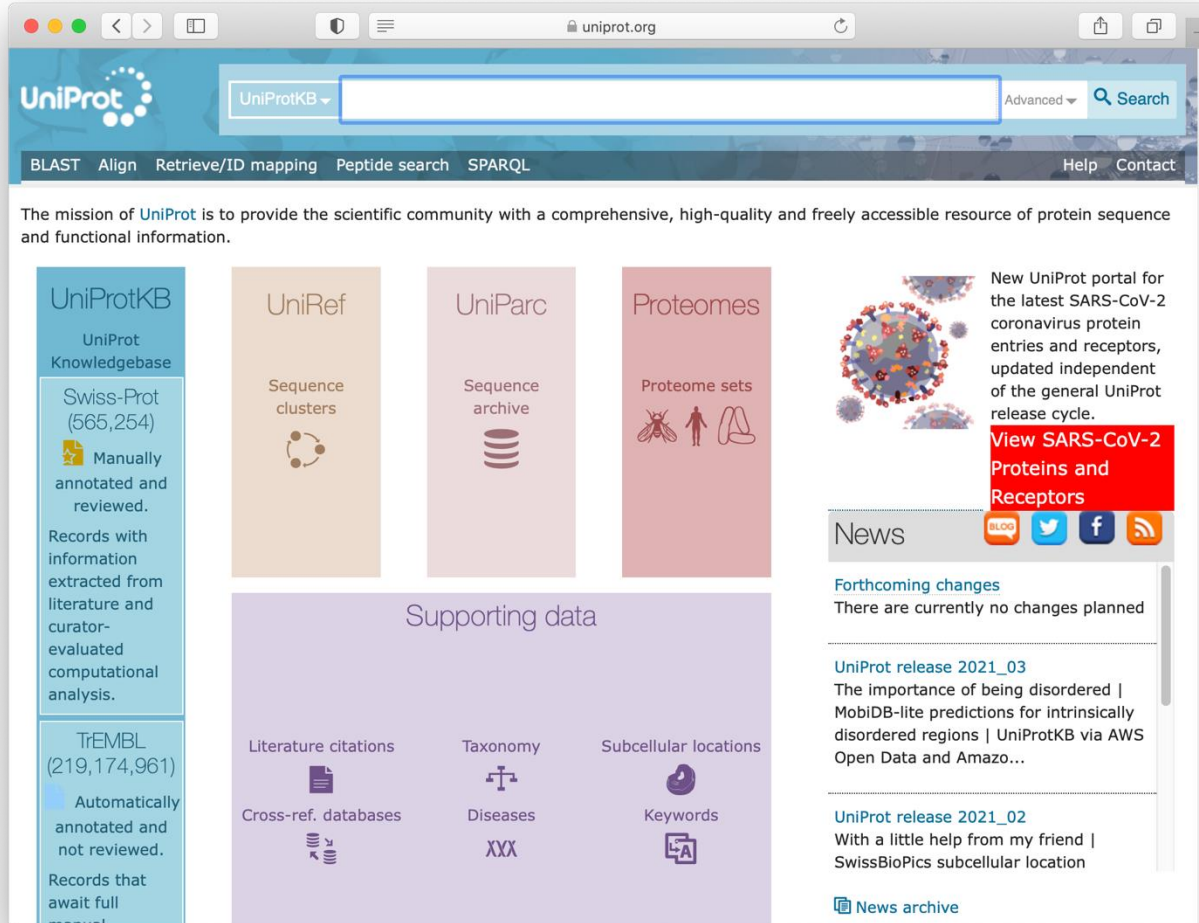
High resolution



Low resolution

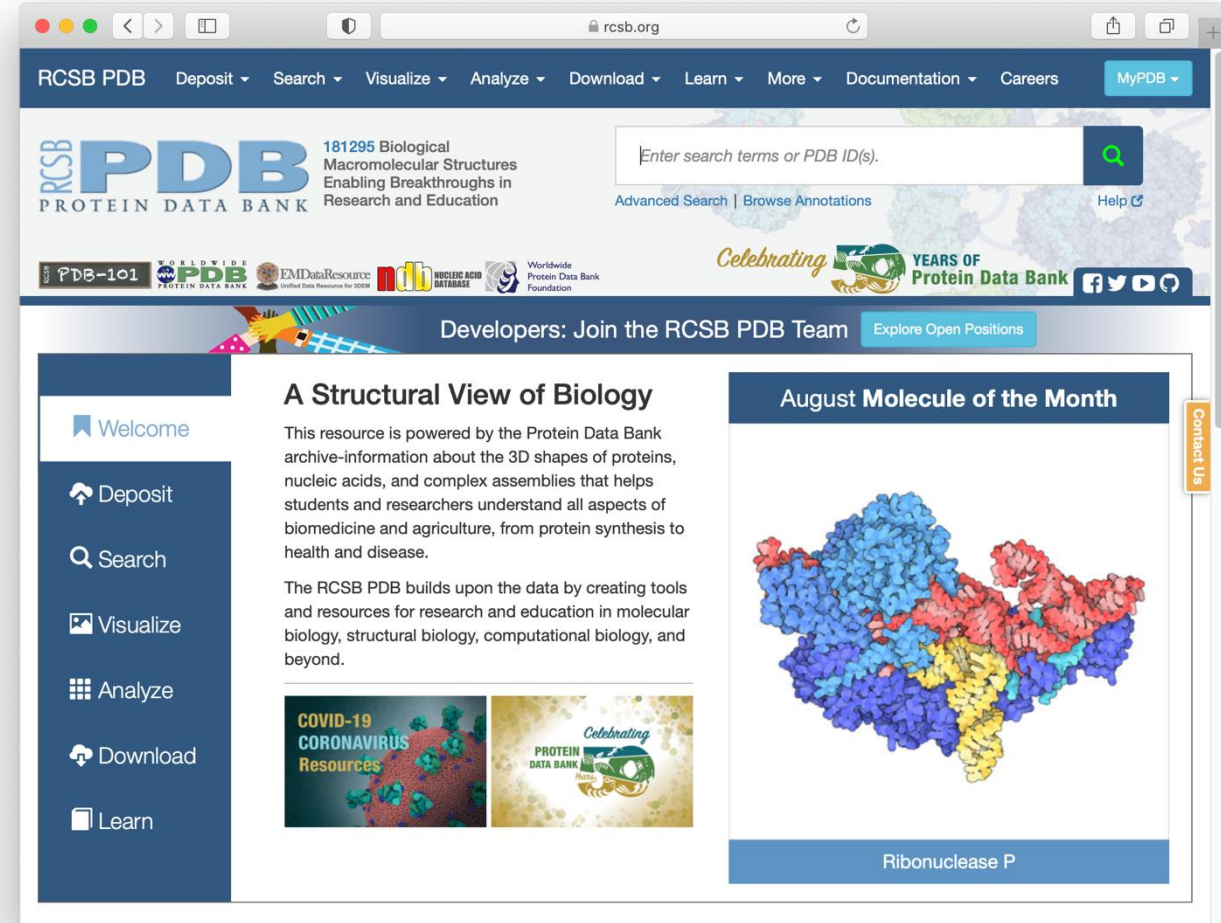
Where to find protein information

UniProt: **U**niversal **P**rotein Resource
www.uniprot.org



protein sequence and functional information

RCSB PDB: **P**rotein **D**ata**B**ank
www.rcsb.org



central repository of biomolecular structures

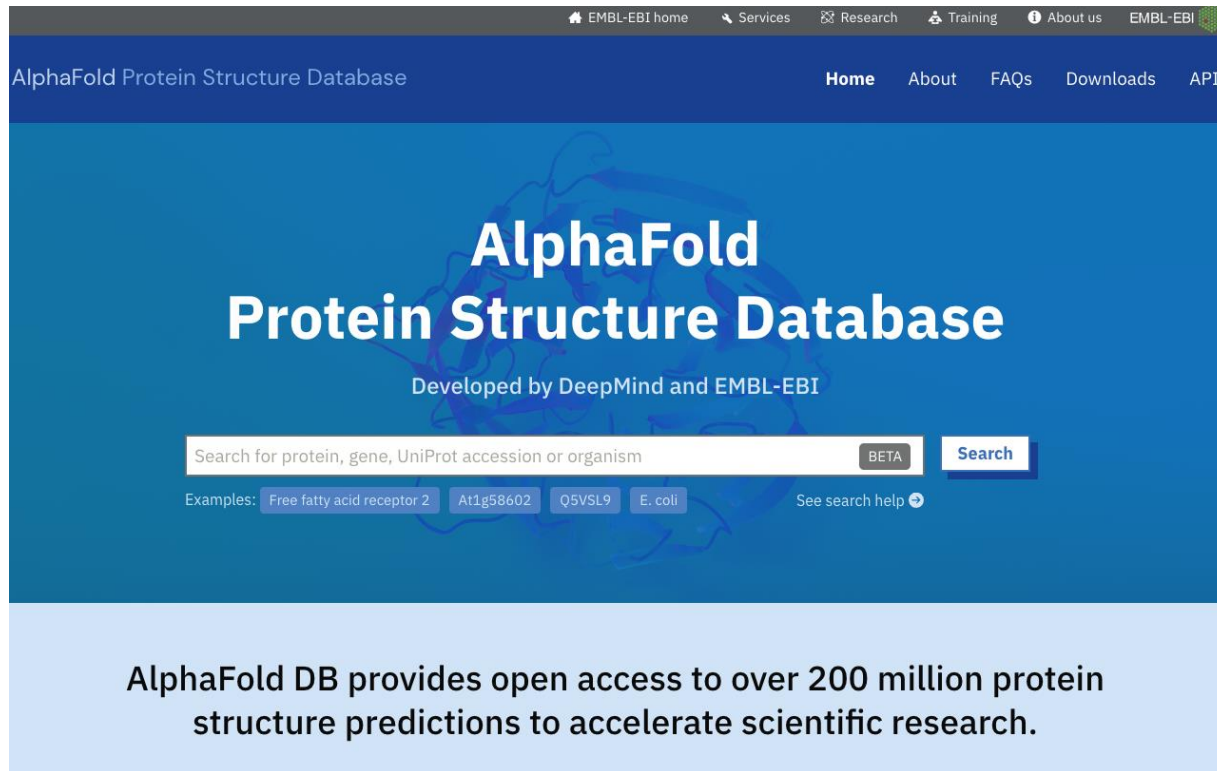
AlphaFold

Database: <https://alphafold.ebi.ac.uk/>

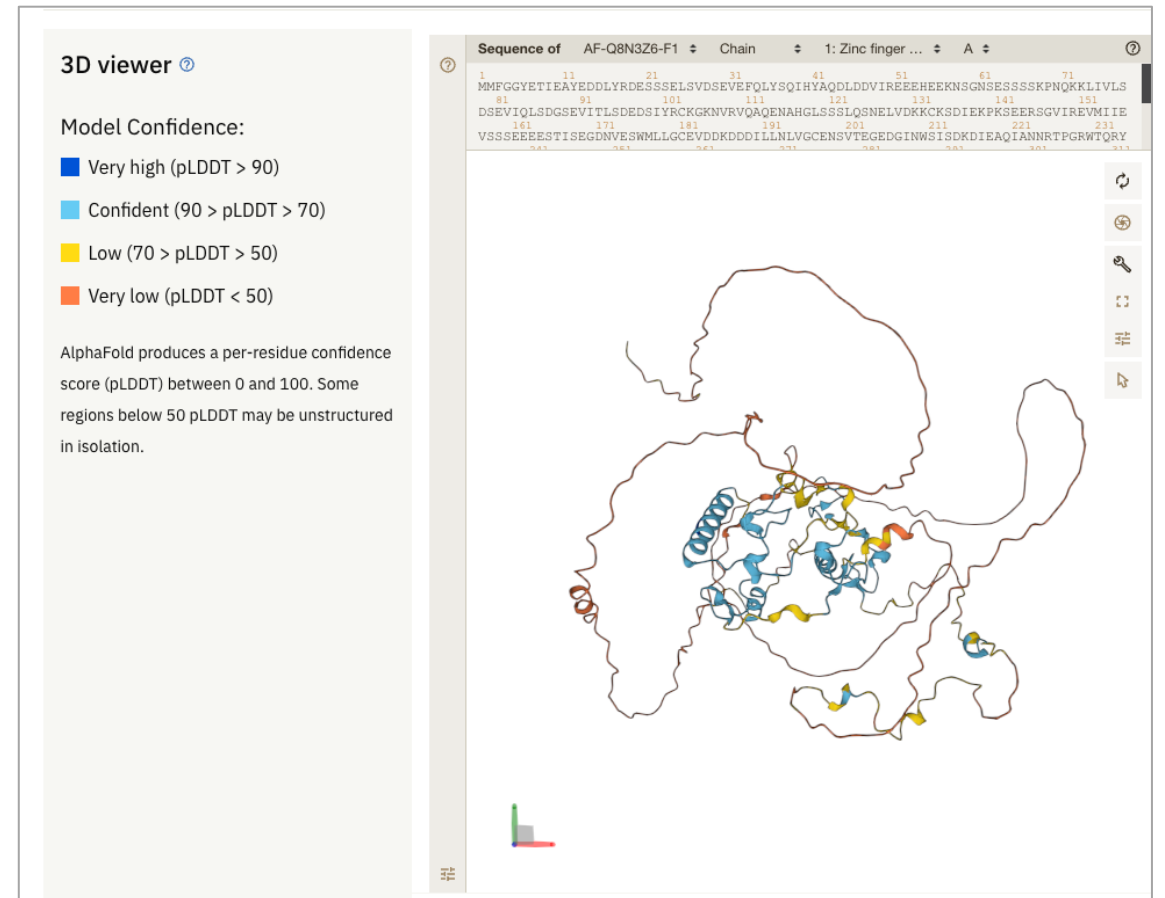
models for almost every protein in Uniprot

Revolutionary tool for structural biology, but proteins are chaotic

post-translational modifications (PTMs), environment, ligands, oligomerization etc...



The screenshot shows the homepage of the AlphaFold Protein Structure Database. The header includes navigation links: EMBL-EBI home, Services, Research, Training, About us, and EMBL-EBI. Below the header, the site is identified as the AlphaFold Protein Structure Database, developed by DeepMind and EMBL-EBI. A search bar prompts users to search for protein, gene, UniProt accession, or organism, with a 'BETA' label and a 'Search' button. Examples of search terms are provided: Free fatty acid receptor 2, A1g58602, Q5VSL9, and E. coli. A link to 'See search help' is also present. At the bottom, a light blue banner states: 'AlphaFold DB provides open access to over 200 million protein structure predictions to accelerate scientific research.'



The screenshot displays the 3D viewer interface for protein AF-Q8N3Z6-F1. On the left, the '3D viewer' section shows the 'Model Confidence' legend: Very high (pLDDT > 90) in blue, Confident (90 > pLDDT > 70) in light blue, Low (70 > pLDDT > 50) in yellow, and Very low (pLDDT < 50) in orange. A note states: 'AlphaFold produces a per-residue confidence score (pLDDT) between 0 and 100. Some regions below 50 pLDDT may be unstructured in isolation.' The main area shows a 3D ribbon diagram of the protein structure, with different regions colored according to the confidence scale. A sequence viewer at the top right displays the protein sequence: MMFGGYETIEAYEDDLYRDESSSELSVDSEVEFQYLSQIHYAODLDDVIREEEHEEKNSGNSSESSSKPNQKKLIVLS... and includes a search bar and navigation icons.

<https://alphafold.ebi.ac.uk/entry/Q8N3Z6>

Useful resources

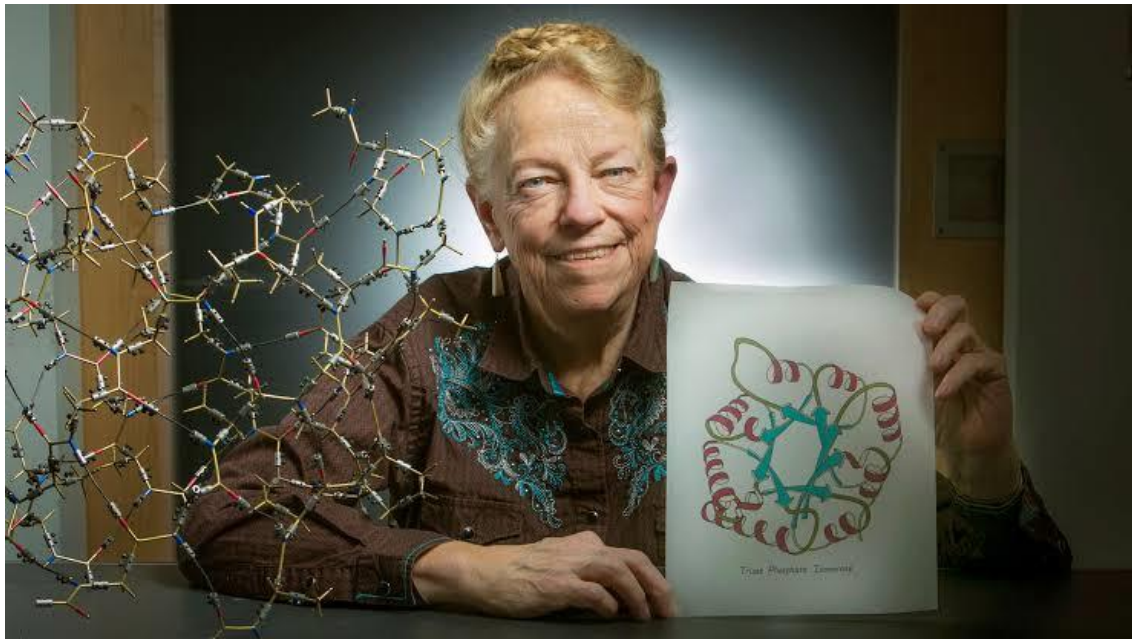
Name	Link	Purpose
UniProt	https://www.uniprot.org/	Protein information database
Protein Data Bank (PDB)	https://www.rcsb.org/	Protein structure repository
PyMOL	https://pymol.org/	Download PyMOL
PyMOL wiki	www.pymolwiki.org	Information on PyMOL such as examples of settings
ConSurf	http://consurf.tau.ac.il	Evolutionary conservation of amino/nucleic acid sequences
PISA	www.ebi.ac.uk/pdbe/pisa/	Protein interface and assemblies
Dali	http://ekhidna2.biocenter.helsinki.fi/dali/	Search PDB for similar structures
EMDB	https://www.ebi.ac.uk/emdb/	Repository for EM/ET data
AlphaFold database	https://alphafold.ebi.ac.uk/	Database of AlphaFold predictions
ChimeraX	https://www.cgl.ucsf.edu/chimerax/	Another visualization software, works well with EM maps

overview of structure files

model

- the coordinates of the atoms
- file types: .pdb, .cif

Note: Cartoon (ribbon) representation is an artistic interpretation of structures invented by Dr. Jane Richardson (Duke)



map

- the experimental data with which you can place atoms into position (x-ray or EM)
- can also be called structure factors or map coefficients
- file types: .map, .mrc, .ccp4, .mtz, .cif



emd_27829.map									
1	2c01	0000	2c01	0000	2c01	0000	0200	0000	
2	0000	0000	0000	0000	0000	0000	2c01	0000	
3	2c01	0000	2c01	0000	0000	4943	0000	4943	
4	0000	4943	0000	b442	0000	b442	0000	b442	
5	0100	0000	0200	0000	0300	0000	9a89	00bf	
6	ecc7	3c3f	34c1	c1b8	0100	0000	0000	0000	
7	0000	0000	0000	0000	0000	0000	0000	0000	
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9	0000	0000	0000	0000	0000	0000	0000	0000	
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13	0000	0000	0000	0000	0000	0000	0000	0000	
14	4d41	5020	4441	0000	e0eb	913c	0100	0000	
15	3a3a	3a3a	454d	4441	5441	4241	4e4b	2e6f	
16	7267	3a3a	3a3a	454d	442d	3237	3832	393a	
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18	2020	2020	2020	2020	2020	2020	2020	2020	
19	2020	2020	2020	2020	2020	2020	2020	2020	
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22	2020	2020	2020	2020	2020	2020	2020	2020	
23	2020	2020	2020	2020	2020	2020	2020	2020	
24	2020	2020	2020	2020	2020	2020	2020	2020	

The primary information stored in the PDB archive consists of coordinate files that list of atoms and their 3D location in space stored as plain text (ASCII) files
Either as .pdb or mmCIF (.cif) format

1f88.pdb

HEADER

SIGNALING PROTEIN

29-JUN-00

1F88

TITLE

CRYSTAL STRUCTURE OF BOVINE RHODOPSIN

CAVEAT

1F88 MAN E 3 HAS WRONG CHIRALITY AT ATOM C1

COMPND

MOL_ID: 1;

COMPND

2 MOLECULE: RHODOPSIN;

COMPND

3 CHAIN: A, B

SOURCE

MOL_ID: 1;

SOURCE

2 ORGANISM_SCIENTIFIC: BOS TAURUS;

SOURCE

3 ORGANISM_COMMON: CATTLE;

SOURCE

4 ORGANISM_TAXID: 9913;

SOURCE

5 ORGAN: RETINA;

SOURCE

6 OTHER_DETAILS: BOVINE RETINA, ROD CELL OUTER SEGMENTS

KEYWDS

PHOTORECEPTOR, G PROTEIN-COUPLED RECEPTOR, MEMBRANE PROTEIN, RETINAL

KEYWDS

2 PROTEIN, VISUAL PIGMENT, SIGNALING PROTEIN

EXPDTA

X-RAY DIFFRACTION

AUTHOR

T.OKADA,K.PALCZEWSKI,R.E.STENKAMP,M.MIYANO

REVDAT

5

29-JUL-20

1F88

1

CAVEAT

COMPND

REMARK

HETNAM

REVDAT

5

2

1

LINK

SITE

ATOM

REVDAT

4

13-JUL-11

1F88

1

VERSN

REVDAT

3

24-FEB-09

1F88

1

VERSN

REVDAT

2

19-AUG-08

1F88

1

REMARK

REVDAT

1

04-AUG-00

1F88

0

ATOM

16

ND2

ASN

A

2

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-23.187

1.00

59.21

N

ATOM

17

N

GLY

A

3

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-2.466

-23.598

1.00

49.38

N

ATOM

18

CA

GLY

A

3

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-23.332

1.00

48.15

C

ATOM

19

C

GLY

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1.00

47.25

C

ATOM

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GLY

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1.00

48.00

O

ATOM

21

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45.08

N

ATOM

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CA

THR

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-25.494

1.00

44.41

C

ATOM

23

C

THR

A

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1.00

44.61

C

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THR

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1.00

44.85

O

ATOM

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CB

THR

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C

ATOM

26

OG1

THR

A

4

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1.901

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44.84

O

ATOM

27

CG2

THR

A

4

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1.00

43.69

C

ATOM

28

N

GLU

A

5

46.225

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45.88

N

ATOM

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CA

GLU

A

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C

ATOM

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GLU

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C

ATOM

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GLU

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CG

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C

ATOM

34

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GLU

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52.49

C

ATOM

35

OE1

GLU

A

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1.511

-28.240

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55.51

O

ATOM

36

OE2

GLU

A

5

52.047

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1.00

51.62

O

ATOM

37

N

GLY

A

6

47.387

5.855

-27.102

1.00

48.23

N

Header

Atom coordinates

Header

Atom coordinates

what's in a pdb file

atom #, atom name, residue name, chain id, residue number, x/y/z coordinates of the atom, occupancy, bfactor, atom element

1	HEADER	RNA BINDING PROTEIN/RNA	14-AUG-22	8E29
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4	COMPND	2 MOLECULE: DIS3-LIKE EXONUCLEASE 2;		
5	COMPND	3 CHAIN: A;		
6	COMPND	4 SYNONYM: HDIS3L2;		
7	COMPND	5 EC: 3.1.13.-;		
8	COMPND	6 ENGINEERED: YES;		
9	COMPND	7 MOL_ID: 2;		
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11	COMPND	9 CHAIN: B;		
12	COMPND	10 ENGINEERED: YES		
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15	SOURCE	3 ORGANISM_COMMON: HUMAN;		
16	SOURCE	4 ORGANISM_TAXID: 9606;		
17	SOURCE	5 GENE: DIS3L2, FAM6A;		
18	SOURCE	6 EXPRESSION_SYSTEM: SPODOPTERA FRUGIPERDA;		
19	SOURCE	7 EXPRESSION_SYSTEM_TAXID: 7108;		
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21	SOURCE	9 SYNTHETIC: YES;		
22	SOURCE	10 ORGANISM_SCIENTIFIC: SYNTHETIC CONSTRUCT;		
23	SOURCE	11 ORGANISM_TAXID: 32630		
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25	KEYWDS	2 BINDING PROTEIN-RNA COMPLEX		
26	EXPDTA	ELECTRON MICROSCOPY		

8e29.pdb																		
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456	SHEET	3	AA1	6 ARG	A	231	GLU	A	240	-1	0	TYR	A	237	N	VAL	A	112
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458	SHEET	5	AA1	6 GLU	A	82	ILE	A	85	-1	N	ILE	A	85	0	ILE	A	94
459	SHEET	6	AA1	6 ARG	A	74	ILE	A	75	-1	N	ARG	A	74	0	PHE	A	84
460	SHEET	1	AA2	6 ALA	A	246	LYS	A	252	0								
461	SHEET	2	AA2	6 TYR	A	265	PRO	A	270	-1	0	LEU	A	267	N	LYS	A	252
462	SHEET	3	AA2	6 ILE	A	278	PRO	A	281	-1	0	VAL	A	280	N	ALA	A	266
463	SHEET	4	AA2	6 ALA	A	315	GLY	A	324	1	0	ALA	A	315	N	TYR	A	279
464	SHEET	5	AA2	6 LEU	A	300	ASP	A	307	-1	N	ILE	A	302	0	ALA	A	320
465	SHEET	6	AA2	6 ALA	A	246	LYS	A	252	-1	N	ALA	A	247	0	CYS	A	203

513	ATOM	20	N	GLU	A	51	87.388	80.367	121.779	1.00	85.42	N
514	ATOM	21	CA	GLU	A	51	86.228	79.551	121.454	1.00	85.42	C
515	ATOM	22	C	GLU	A	51	86.500	78.738	120.196	1.00	85.42	C
516	ATOM	23	O	GLU	A	51	87.163	79.215	119.271	1.00	85.42	O
517	ATOM	24	CB	GLU	A	51	84.981	80.405	121.263	1.00	85.42	C
518	ATOM	25	CG	GLU	A	51	83.734	79.732	121.773	1.00	85.42	C
519	ATOM	26	CD	GLU	A	51	82.477	80.461	121.378	1.00	85.42	C
520	ATOM	27	OE1	GLU	A	51	82.293	80.702	120.169	1.00	85.42	O
521	ATOM	28	OE2	GLU	A	51	81.670	80.783	122.274	1.00	85.42	O
522	ATOM	29	N	THR	A	52	85.998	77.507	120.177	1.00	86.60	N
523	ATOM	30	CA	THR	A	52	86.234	76.597	119.068	1.00	86.60	C
524	ATOM	31	C	THR	A	52	85.477	77.029	117.819	1.00	86.60	C
525	ATOM	32	O	THR	A	52	84.455	77.710	117.882	1.00	86.60	O
526	ATOM	33	CB	THR	A	52	85.797	75.186	119.437	1.00	86.60	C
527	ATOM	34	OG1	THR	A	52	84.375	75.100	119.320	1.00	86.60	O
528	ATOM	35	CG2	THR	A	52	86.189	74.865	120.861	1.00	86.60	C
529	ATOM	36	N	TYR	A	53	85.988	76.602	116.670	1.00	86.91	N
530	ATOM	37	CA	TYR	A	53	85.354	76.896	115.395	1.00	86.91	C
531	ATOM	38	C	TYR	A	53	84.110	76.027	115.212	1.00	86.91	C
532	ATOM	39	O	TYR	A	53	83.850	75.102	115.982	1.00	86.91	O
533	ATOM	40	CB	TYR	A	53	86.329	76.677	114.245	1.00	86.91	C
534	ATOM	41	CG	TYR	A	53	87.400	77.727	114.118	1.00	86.91	C
535	ATOM	42	CD1	TYR	A	53	88.429	77.574	113.214	1.00	86.91	C
536	ATOM	43	CD2	TYR	A	53	87.373	78.876	114.883	1.00	86.91	C
537	ATOM	44	CE1	TYR	A	53	89.401	78.522	113.088	1.00	86.91	C
538	ATOM	45	CE2	TYR	A	53	88.344	79.831	114.759	1.00	86.91	C
539	ATOM	46	CZ	TYR	A	53	89.350	79.648	113.862	1.00	86.91	C
540	ATOM	47	OH	TYR	A	53	90.316	80.599	113.736	1.00	86.91	O
541	ATOM	48	N	MET	A	54	83.333	76.325	114.178	1.00	98.72	N
542	ATOM	49	CA	MET	A	54	82.160	75.527	113.852	1.00	98.72	C
543	ATOM	50	C	MET	A	54	82.382	74.709	112.587	1.00	98.72	C
544	ATOM	51	O	MET	A	54	83.355	74.893	111.854	1.00	98.72	O
545	ATOM	52	CB	MET	A	54	80.920	76.405	113.682	1.00	98.72	C
546	ATOM	53	CG	MET	A	54	80.567	77.235	114.879	1.00	98.72	C
547	ATOM	54	SD	MET	A	54	78.941	77.984	114.674	1.00	98.72	S
548	ATOM	55	CE	MET	A	54	79.049	78.572	112.987	1.00	98.72	C
549	ATOM	56	N	SER	A	55	81.452	72.786	112.252	1.00	105.56	N

Why and how to visualize protein structures?

- To observe and analyze a structure of interest.
- To make images or movies to illustrate certain properties of the structure of interest.
- There are numerous programs and websites to visualize macromolecular structures. PyMOL and UCSF Chimera / ChimeraX are most used.

PyMOL tutorial

PyMOL interface

top menu bar

undo is unreliable

mouse selection mode
i.e. what will get
selected when you
click on the molecule

Zoom/Orient to
reset the view

display area

Log

command line

object panel

each object
have their own
buttons:
[A]ction
[S]how
[H]ide
[L]abel
[C]olor

In this ppt,
[square brackets]
indicates these
buttons

Wizards Menu

The screenshot shows the PyMOL interface with a central display area containing a 3D molecular model of a protein-DNA complex. The top menu bar includes File, Edit, Build, Movie, Display, Setting, Scenes, Mouse, Wizard, Plugin, and Help. Below the menu bar is a toolbar with buttons for Residues, Zoom, Orient, Rock, and Presets. The object panel on the right lists objects 'All' and '1tup', each with buttons for Action (A), Show (S), Hide (H), Label (L), and Color (C). The command line at the bottom shows a series of commands and their outputs, including a file not found error and a syntax error. A Wizards Menu is also visible on the right side of the interface.

```
FileNotFoundError: [Errno 2] No such file or directory: ''
PyMOL>open 1tup
File "toplevel", line 1
  open 1tup
  ^
SyntaxError: invalid decimal literal
PyMOL>fetch 1tup
TITLE      TUMOR SUPPRESSOR P53 COMPLEXED WITH DNA
ExecutiveLoad-Detail: Detected mmCIF
CmdLoad: "./1tup.cif" loaded as "1tup".
Setting: bg_rgb set to white.
Setting: opaque_background set to on.
```

1. Loading structures

File > Get PDB > 1tup

OR

1. Go to PDB website: www.rcsb.org

2. Find molecule of interest using search bar

Search for: **p53 complexed with dna**

3. Download Files > PDB Format > 1tup.pdb file

and open it in PyMOL

using File>Open

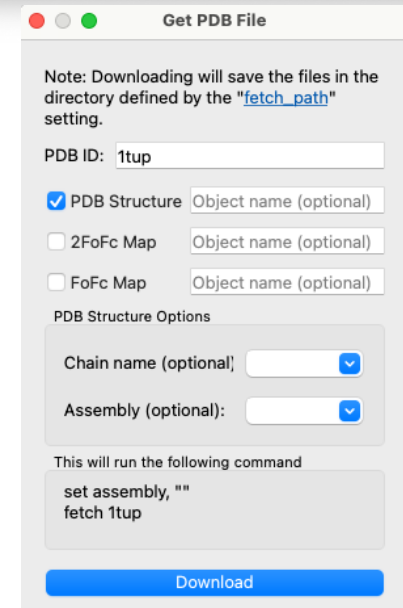
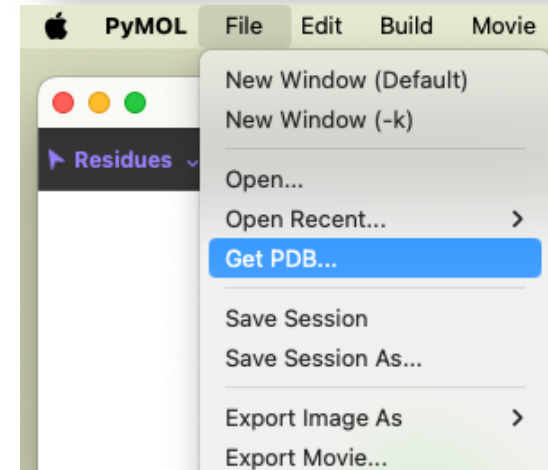
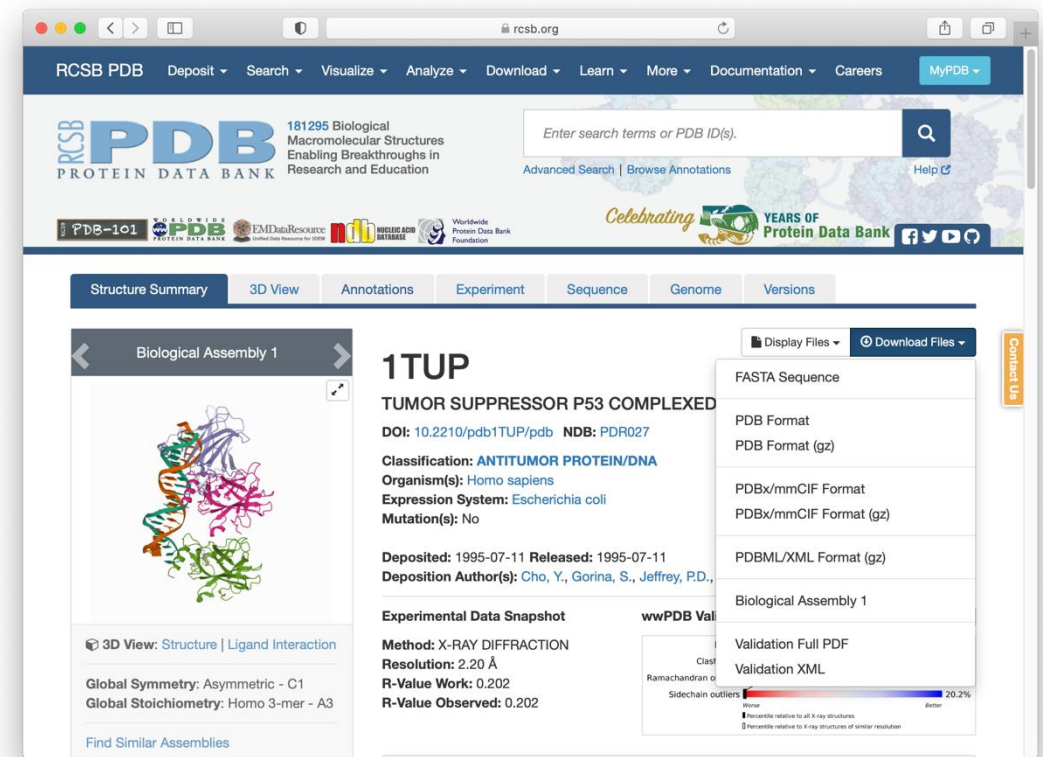
OR

Fetch .pdb file directly to PyMOL using

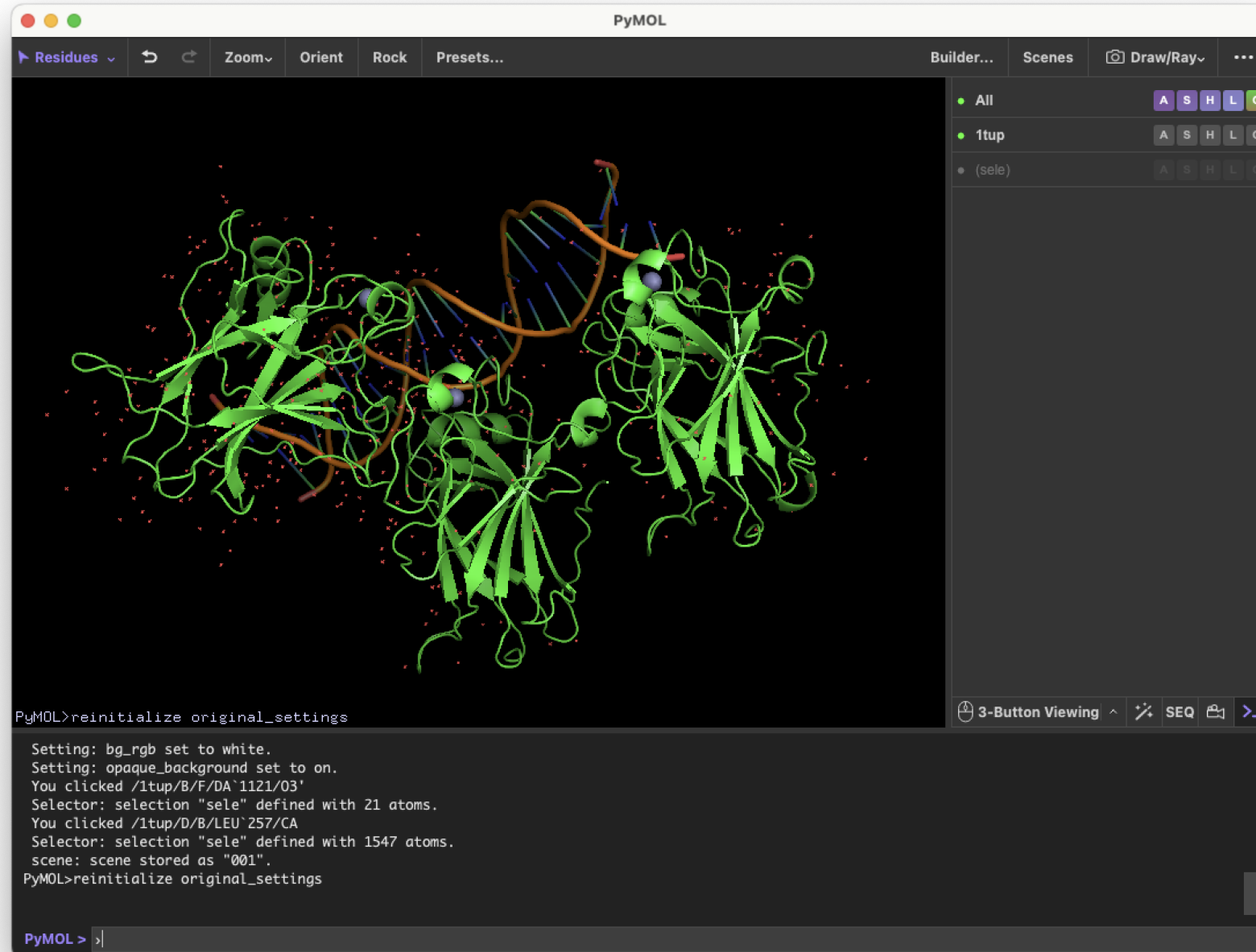
File>Get PDB... and providing 4 letter code from PDB entry: **1TUP**

OR

Command line: `fetch 1tup`

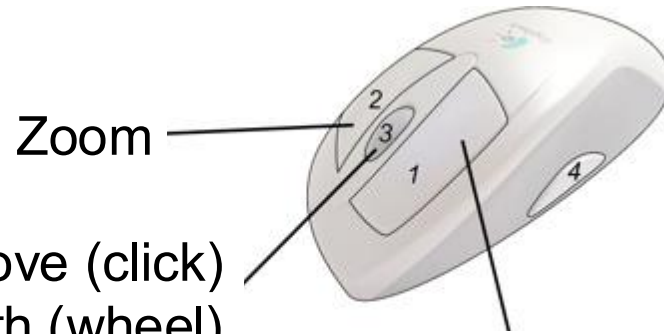


1tup.pdb loaded in PyMOL



2. Mouse controls

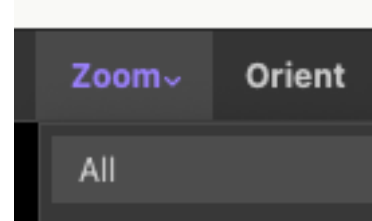
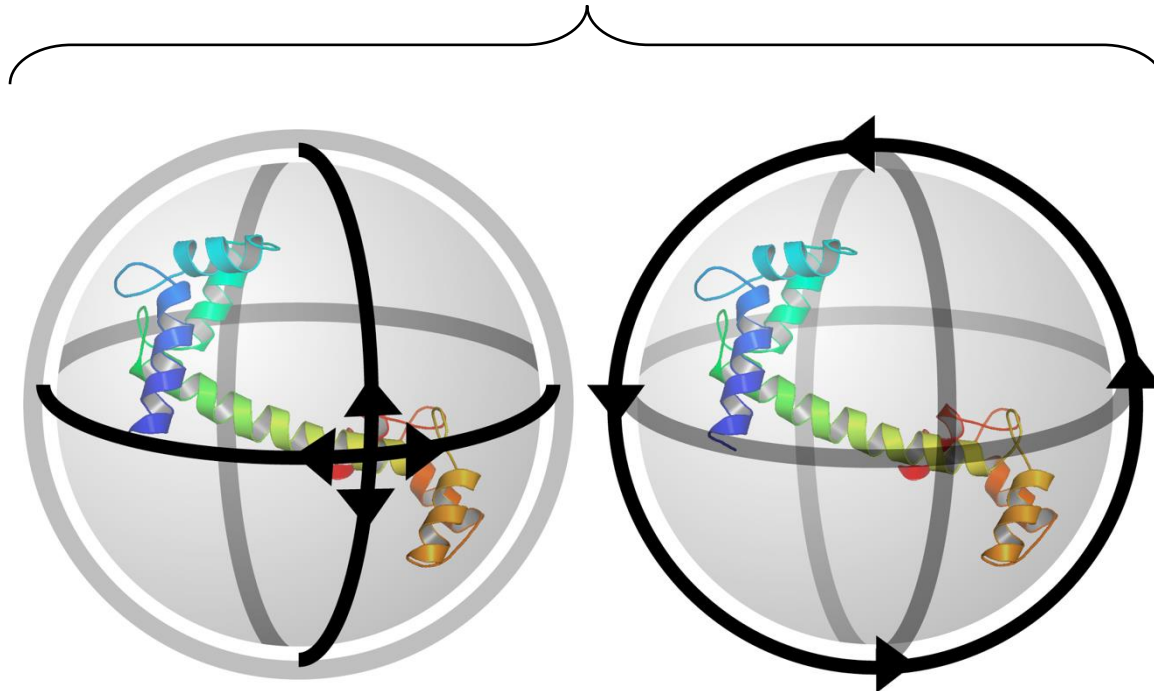
If you get lost:
Zoom>All or Orient



Move (click)

Slab depth (wheel)
and position (Shift + wheel)

Rotate



Mouse functions + modifier keys:

3-Button Viewing Mouse Controls					✓ 3-Button Viewing
					3-Button Editing
					3-Button Lights
					3-Button Motions
Buttons & Keys	L	M	R	Wheel	2-Button Viewing
	Rota	Move	MovZ	Slab	2-Button Selecting
Shift	+Box	-Box	Clip	MovS	2-Button Editing
Ctrl	Move	PkAt	Pk1	MvSZ	2-Button Lights
Ctrl+Shift	Sele	Orig	Clip	MovZ	1-Button Viewing
Single Click	+/-	Cent	Menu		3-Button Maestro
Double Click	Menu	-	PkAt		
					3-Button Viewing ^

Mouse modes



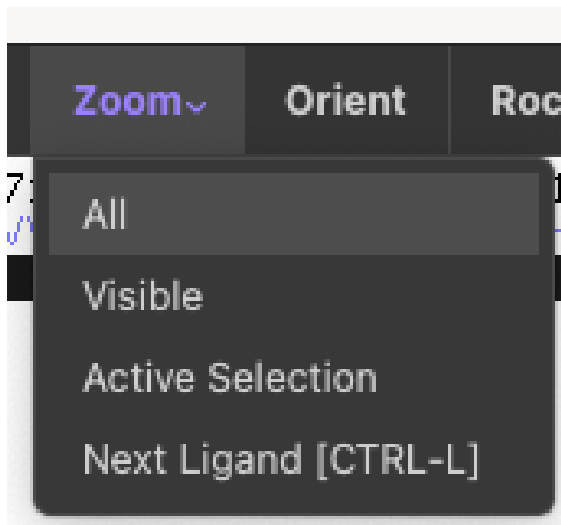
Viewing Mode: view, rotate, translate, and change the representations of objects (you will use this mostly)



Editing Mode: rotate bonds, replace atoms, physically move atoms and residues, etc.

General notes on PyMOL

- Save sessions (**File->Save session...**) from time to time
- Use the **Zoom** or **Orient** buttons on the top panel if you get lost
- To change display quality, select Display > Quality > Maximum quality (or other)



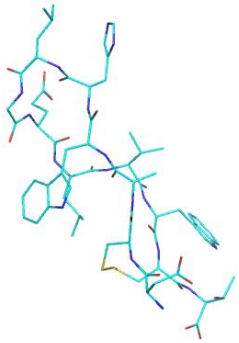
Exercise 1: Adjusting view and slab

1. Reset the view.
 - Locate DNA in the complex, adjust view and slab so you can see single base pair and move the slab so you can see single base-pair as you move the slab along Z-axis.
2. Reset, look around
 - How many protein chains are bound to this dsDNA?
 - Do all the protein chains bind DNA similarly?

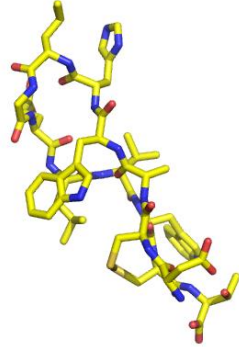


3. Representations

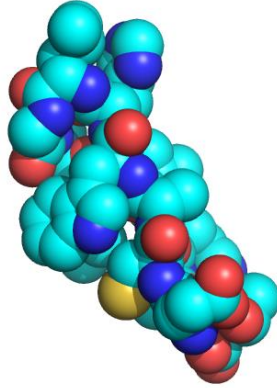
lines



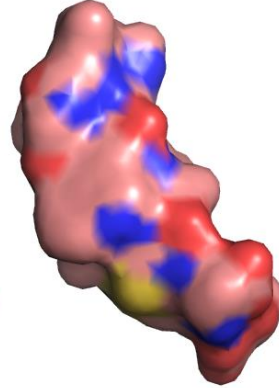
sticks



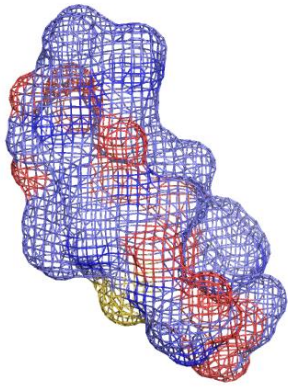
spheres



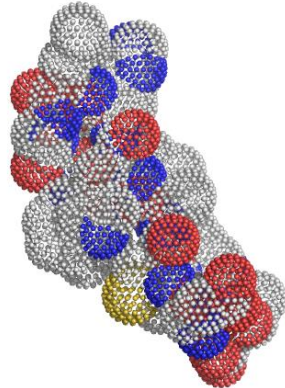
surface



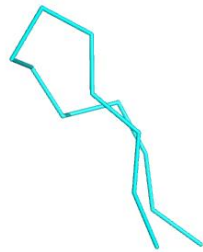
mesh



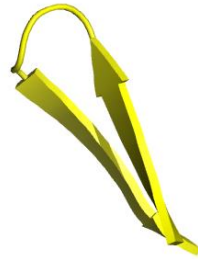
dots



ribbon



cartoon



Different
representations
convey different
information

Object and Selections panel – used to change representations and much more



Selections and objects play slightly different roles in PyMOL.

- An **Object** can be created from selections
 - Can be moved and aligned!
- A **Selection** belongs to a specific object
 - Selections are used to modify representation of parts of an object
 - **You cannot display a selection without displaying its original object source**

4. Selections – how to make them

There are multiple ways to perform selections:

By clicking on the molecule:

- Single left mouse click by default selects single residue
(can also be used to select atom/chain/molecule etc. depending by setting in Mouse->Selection Mode menu)
- Shift + Left Mouse button selects a box

By clicking on the sequence:

- Select Sequence On in the Display Menu to show sequence; click on the residues

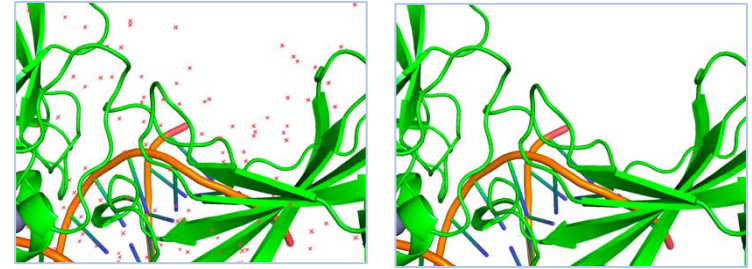
OR

command line: https://pymolwiki.org/index.php/Selection_Algebra

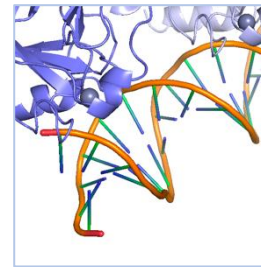
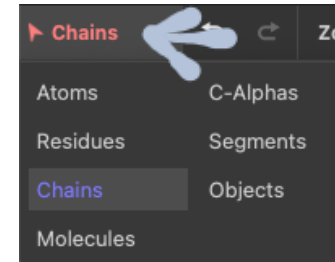
Exercise 2: Changing representations

1. Reset the view.
2. Hide waters:
[H] > waters
3. Select individual protein chains and change their colors:
 - a. Change the mouse selection mode to chains.
 - b. Click on a chain. In the Object Panel, click on [C] button of <sele>, choose a color.
4. Set the DNA representation to licorice sticks and change color by element:
Make sure your mouse selection mode is still chains.
 - a. Click the 2 DNA strands. [S] > as > licorice – sticks.
 - b. [C] > by element > choose a color palette.

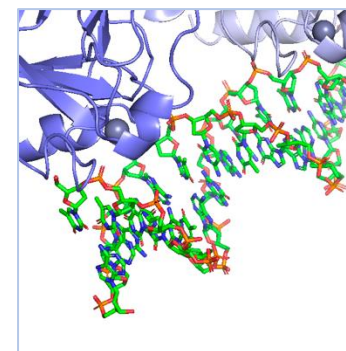
2



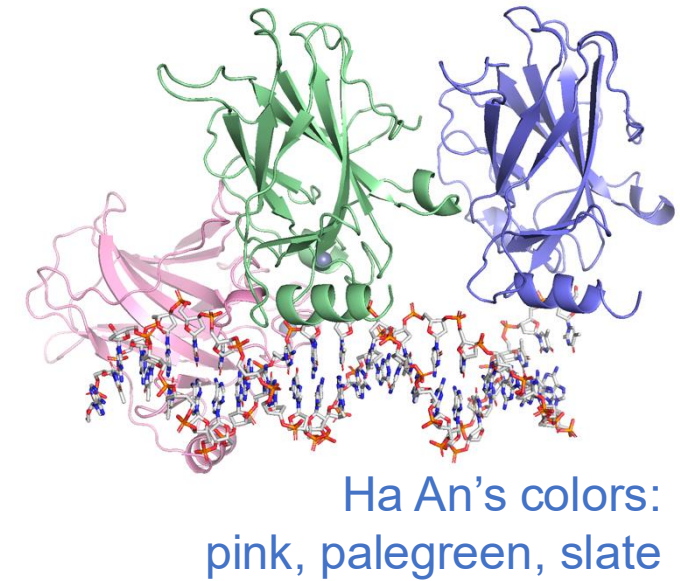
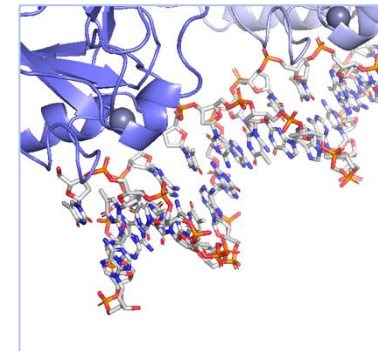
3a



4a



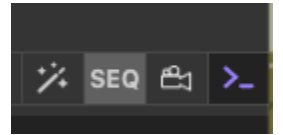
4b



Ha An's colors:
pink, palegreen, slate

Making Selections using Sequence Display

-Select Display->Sequence On to show sequence; click on the residues



```

/1tup 256 261 266 271 276 281 286 291 296 301 306 /F/A/951 /G/B/ /H/C/ /I/E/2024 2084 2204 2300
PILTIITLEDSSGNLLGRNSFEVRVCACPGRDRRTEENLRKKGEPHHELPPGSTKRALPNNT ZN ZN ZN 000000000000000000000000

```

- Colors of sequence corresponds to colors in structure

-0 = water

-Residue number corresponds to the residue directly below the first digit

-Display->Sequence Mode->Residue Names changes Sequence display to three-letter amino acid code

				301						306					311	/F/A/951	/G/B/	/H/C/	/I/E/2024	2035	2048	208	
HIS	GLU	LEU	PRO	PRO	GLY	SER	THR	LYS	ARG	ALA	LEU	PRO	ASN	ASN	THR	ZN	ZN	ZN	HOH	HOH	HOH	HOH	HOH

if you don't see the numbering, might need to change the background color to white (Display > Background > White)

How selections are indicated

Residues 161 166 171 176 181 186 191 196 201 206 211 216 221 226 231 236 241 246 251 256 261

PPGTRVRAMAIYKQSQHMTVVRRCPHHERCSDSDGLAPPQHLIRVEGNLRVEYLDDNTFRHSVVPYEPPEVGSDCTTIHNYMCNSSCMGGMNRRPILTIITLEDSSGNLL

sequence selected

residues selected

Selection (you can rename it too)

Builder... Scenes Draw/Ray...

- All A S H L C
- 1tup A S H L C
- (sele) A S H L C

Selections – command line:

Command line offers powerful way of making selections

Hierarchy: model → chain → resn (residue name) → resi (residue number) → name (atom name)

Examples:

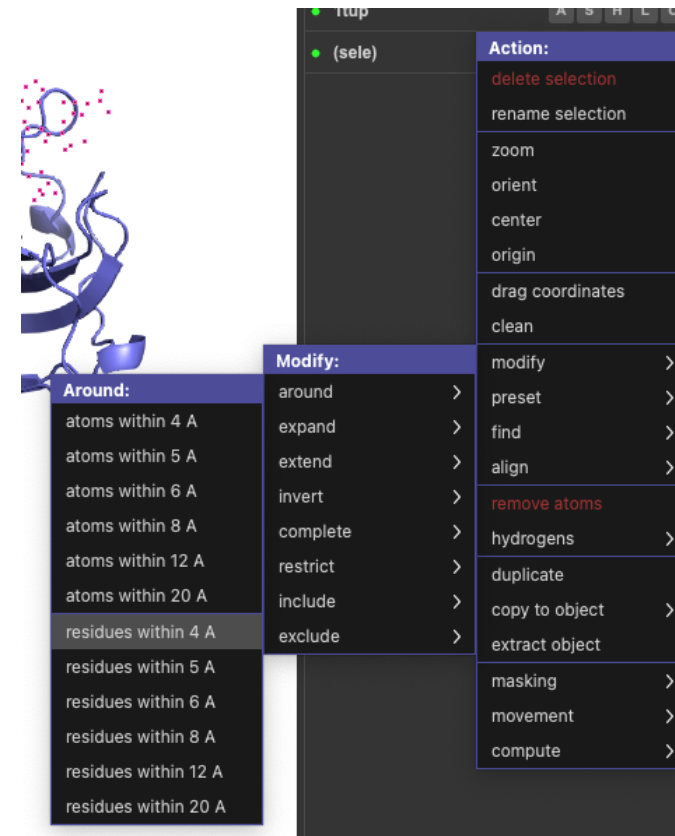
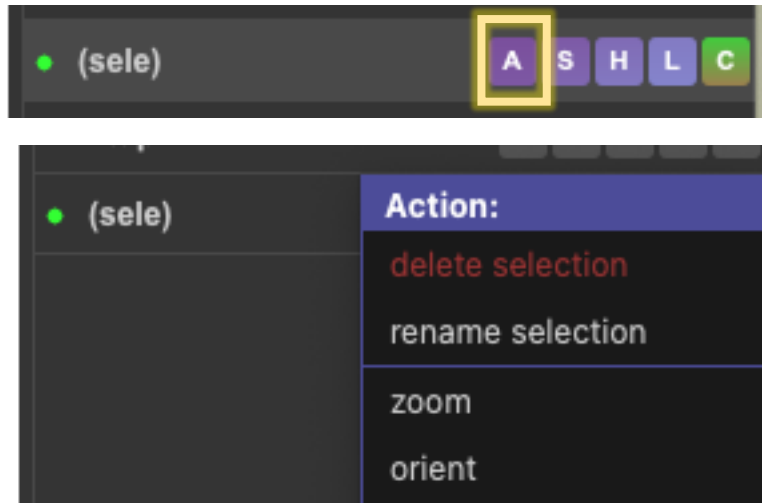
- select chain A – **select chain A**
- select resn lys – **select all lysines**
- select resi 175 – **select residue 175 in all chains**
- select (resi 175 or resi 245) and chain B
 - **select residues 175 and 245 in chain B**
- select interface, (chain B within 4 of chain E:F) or (chain E:F within 4 of chain B) – **make selection named interface with all atoms located less than 4Å apart between chain B and chain E:F**

Type: help select to see help

Full explanation: https://pymolwiki.org/index.php/Selection_Algebra

Selection and Objects

- rename selection: <sele> [A] > rename selection
- copy selection to new object: <sele> [A] > copy to object
- select all residues within 4Å of selection: <sele> [A] > modify > around > residues within 4 A
(this selects the atoms; you can show sidechains by going to [S] > sidechain > stick)



Exercise 3: Working with sequences

Certain residues are most frequently mutated in cancer:

R175, G245, R248, R249, R273, R282.

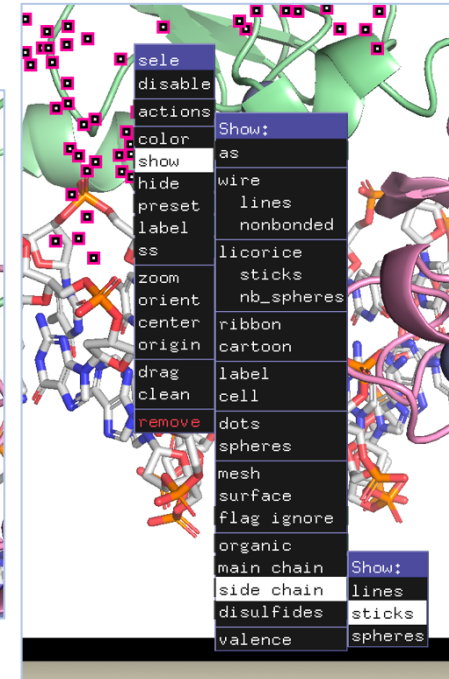
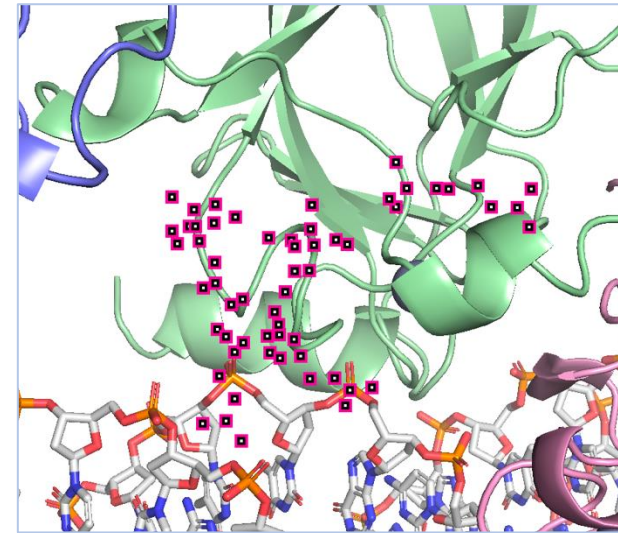
Select and show the side chains for these residues in chain B (middle protein molecule) and look at them.

Q: Where are these residues located?

Q: What could be the role of these residues?

- Display > Sequence
- Make sure your selection mode is 'Residues'

Selecting Residues

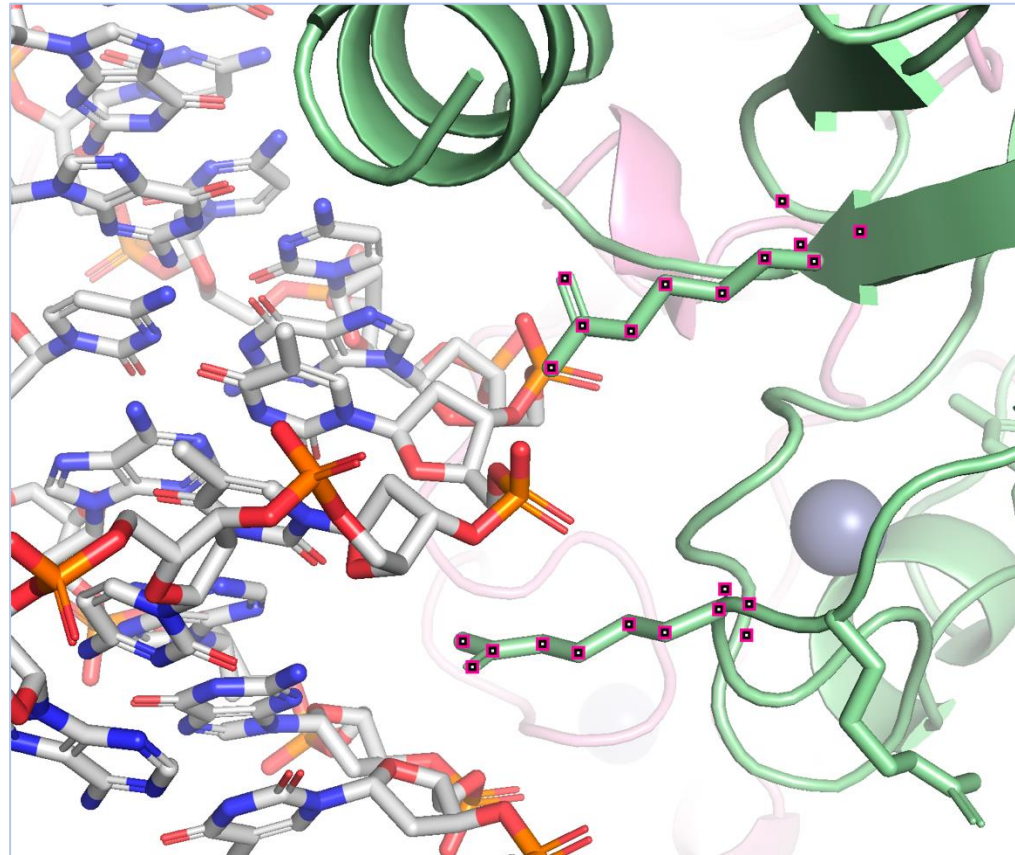


/1tup 141 146 151 156 161 166 171 176 181 186 191 196 201 206 211 216 221 226 231 236 241 246 251 256 261 266 271 276 281 286 291 296 301
FCQLAKTCPVQLWVDSTPPPGTRVRAMAIYKQSQHMTFVVRPCPHHERCSDSDGLAPPQHLIRVEGNLRVEYLDORNTFRHSVVVPYEPPEVVGSDCTTIHNYMCNSSCMCGMNRRIILTITLEDSSGNLLGRNSFEVR/CACPGRRRTTEENLRKKGEPHHELPPGS

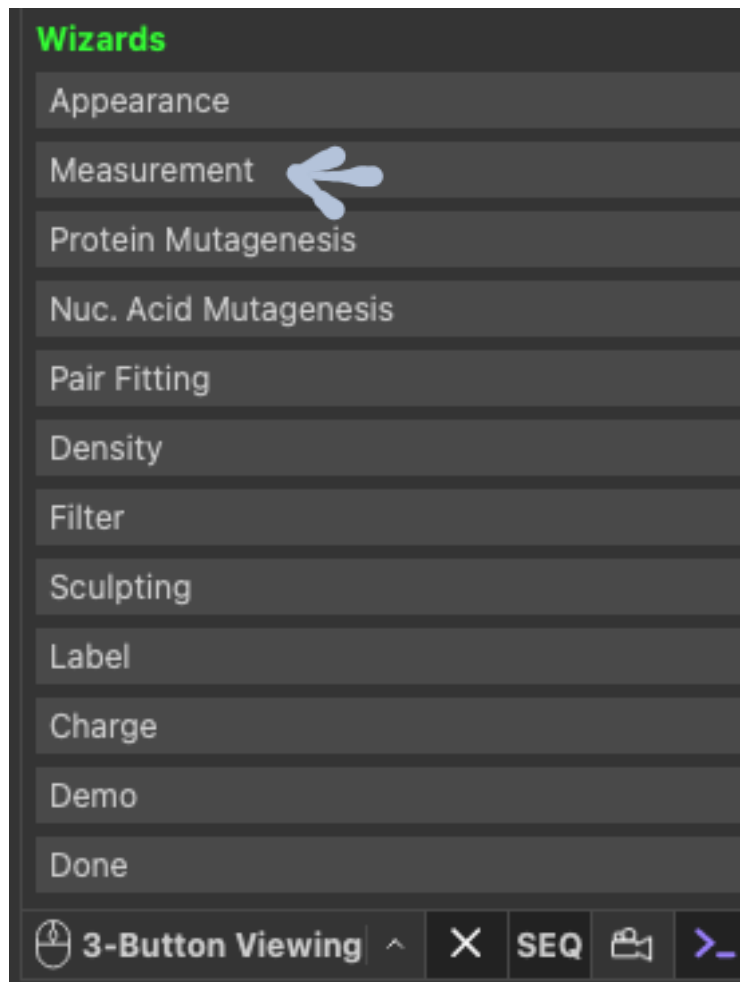
Exercise 3: Working with sequences

Q: Where are these residues located?

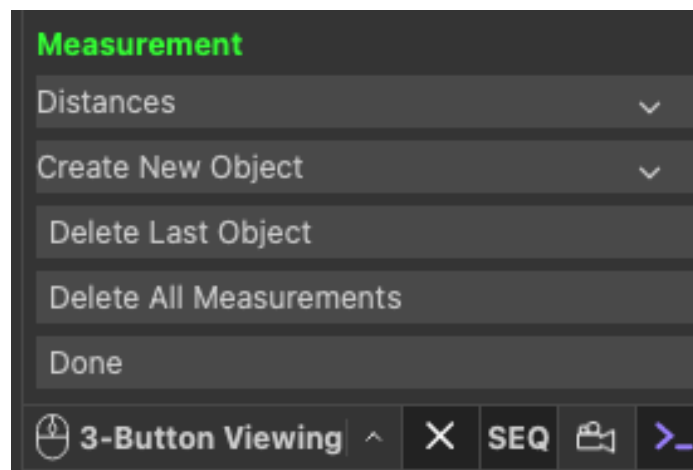
Q: What could be the role of these residues?



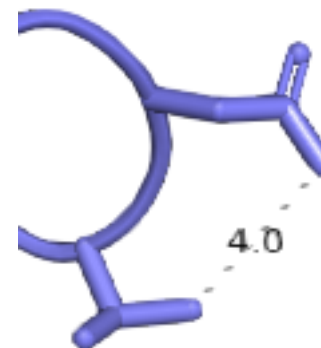
5. Making measurements



Please click on the first atom...

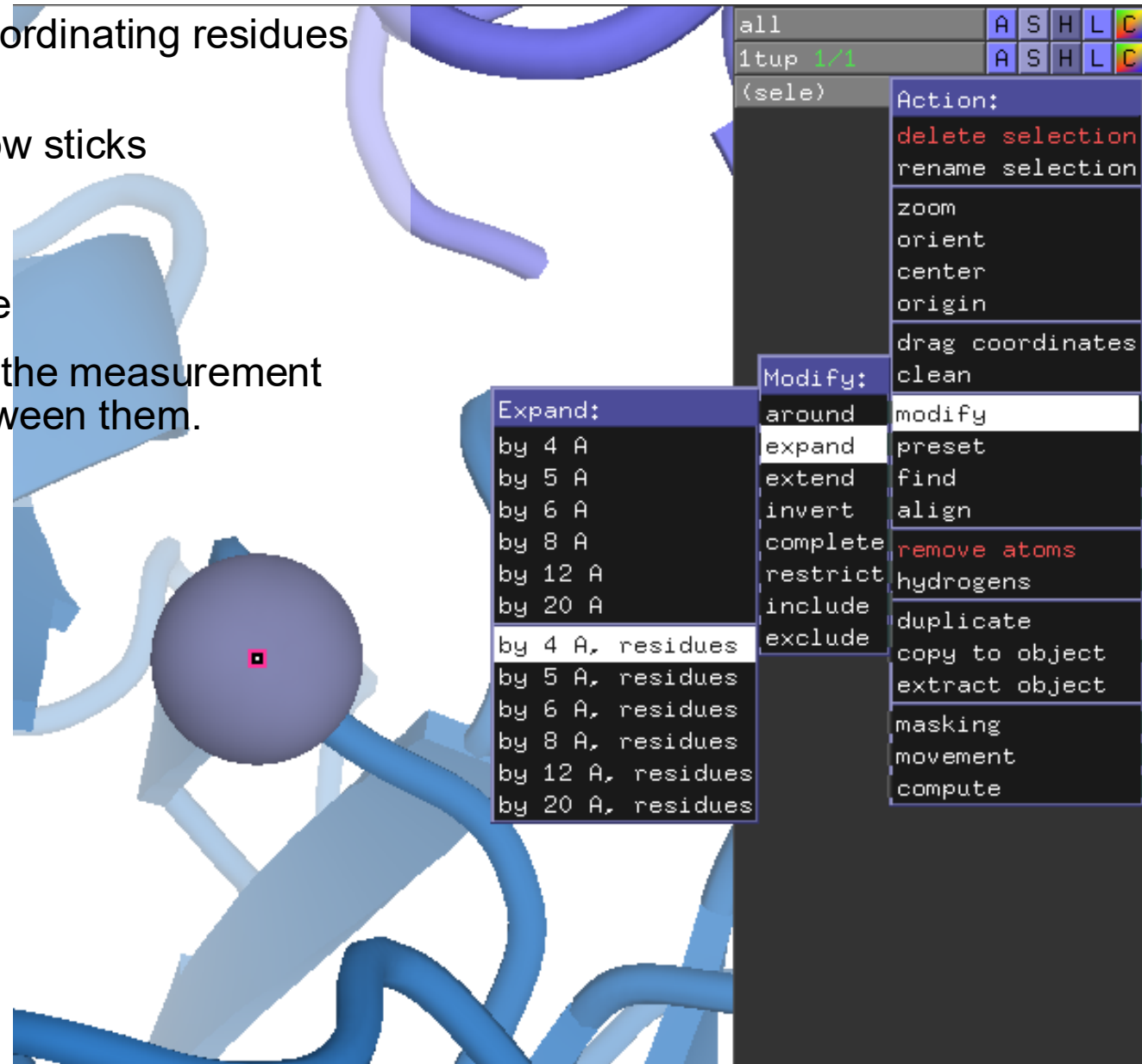


click the first atom, then
click the second atom



Exercise 4: Measure the coordinating distances of the Zn atom

- Select a Zn atom, expand the selection to select coordinating residues
<sele> [A] > modify > expand > by 4 A, residues
- change the representation of the side chains to show sticks
<sele> [S] > sidechain > sticks
- you can also change the color of this selection:
<sele> [C] > by element > choose your color palette
- In the menu bar, Wizard > Measurement to turn on the measurement option click two atoms to measure the distance between them.



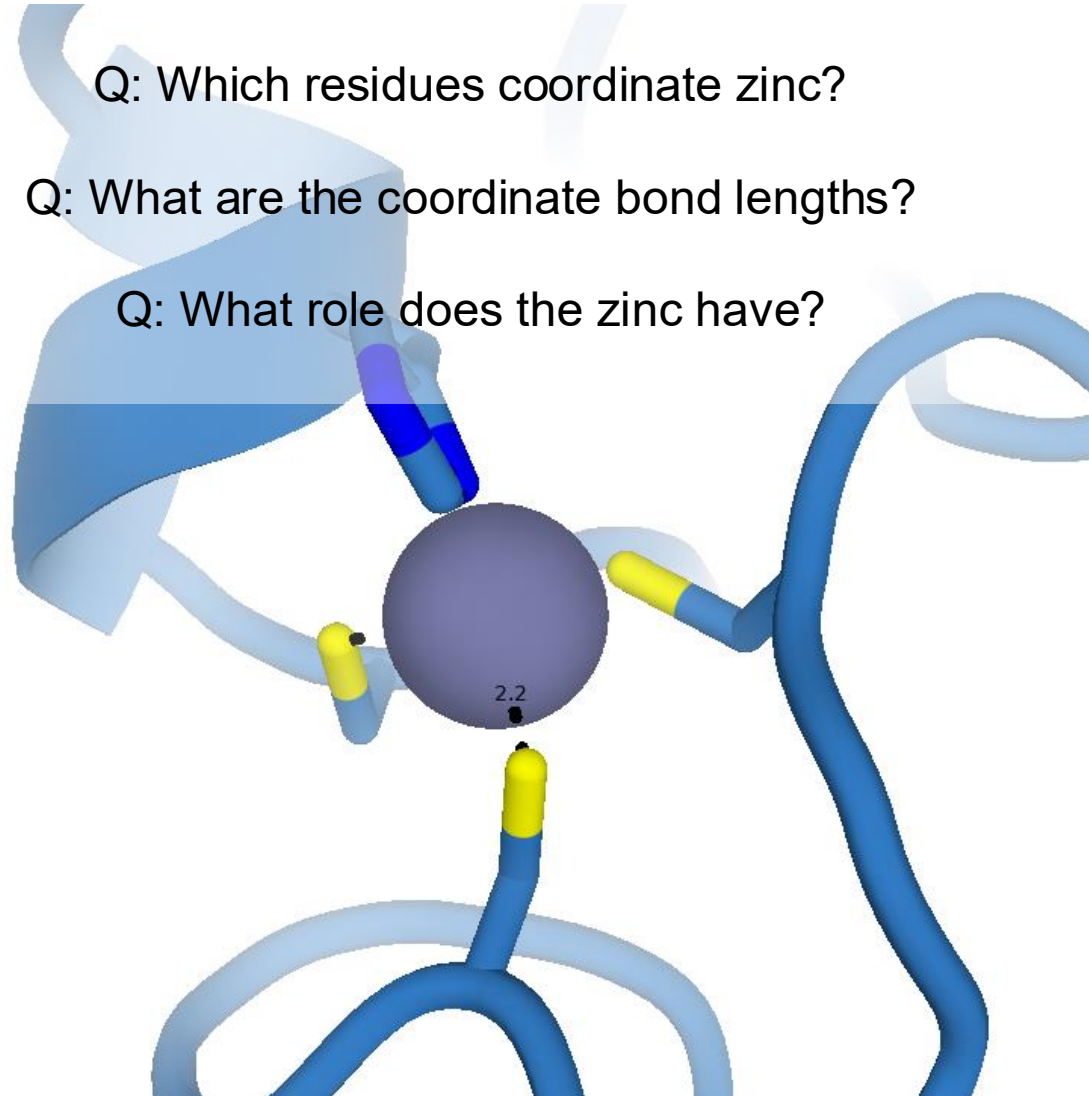
Exercise 4: Measure the coordinating distances of the Zn atom

The zinc ion has been shown to be important in DNA binding.

Q: Which residues coordinate zinc?

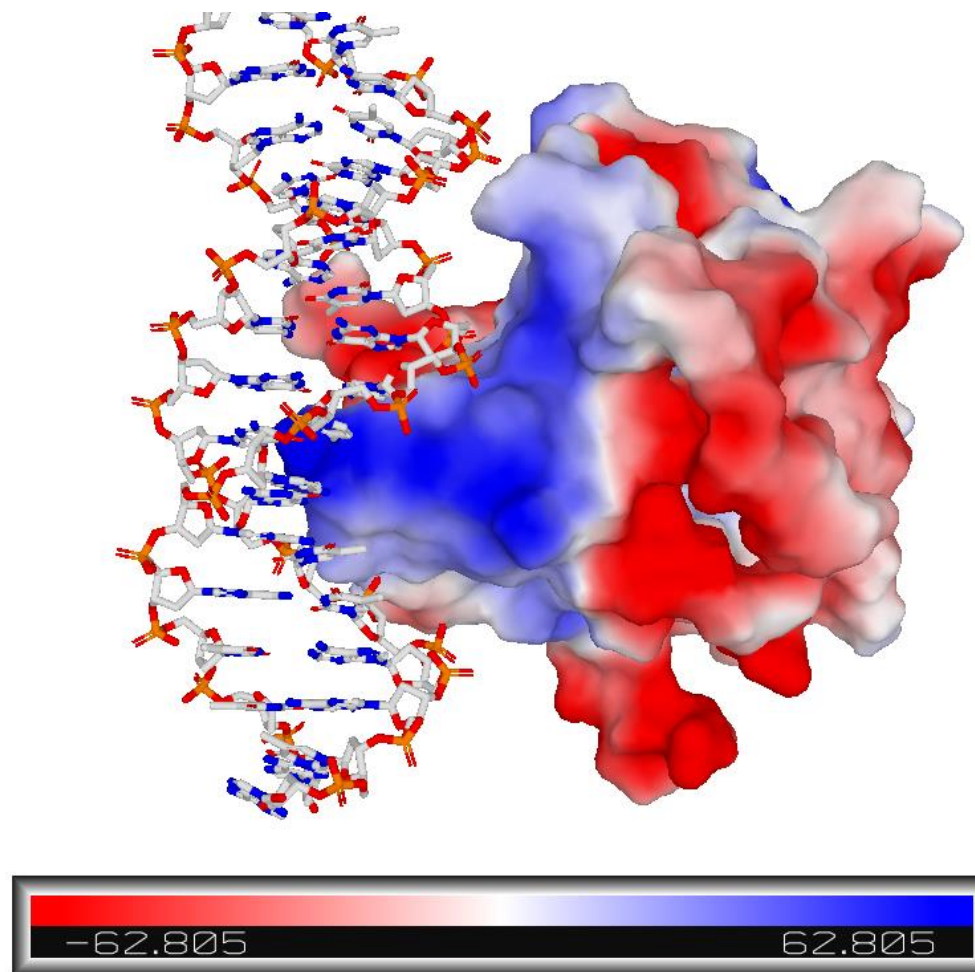
Q: What are the coordinate bond lengths?

Q: What role does the zinc have?



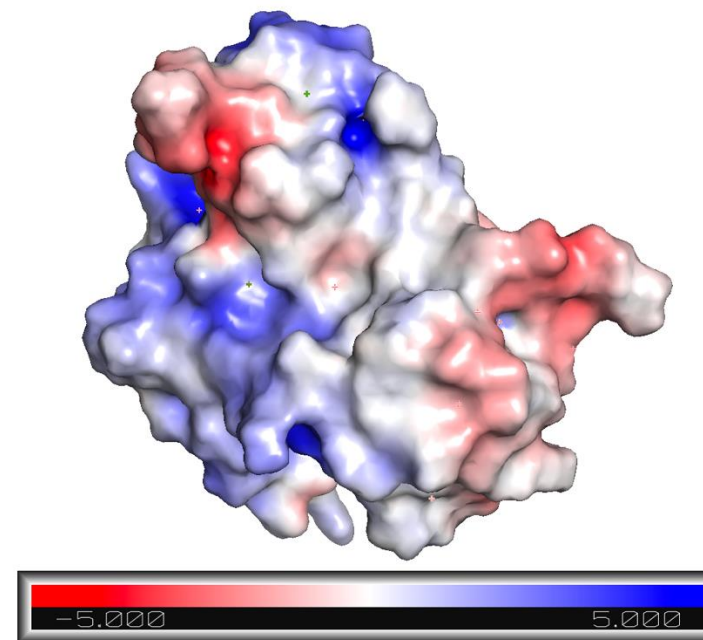
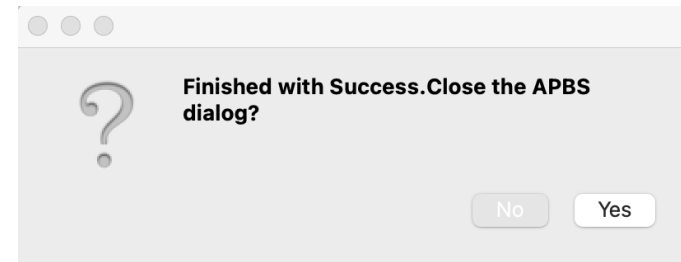
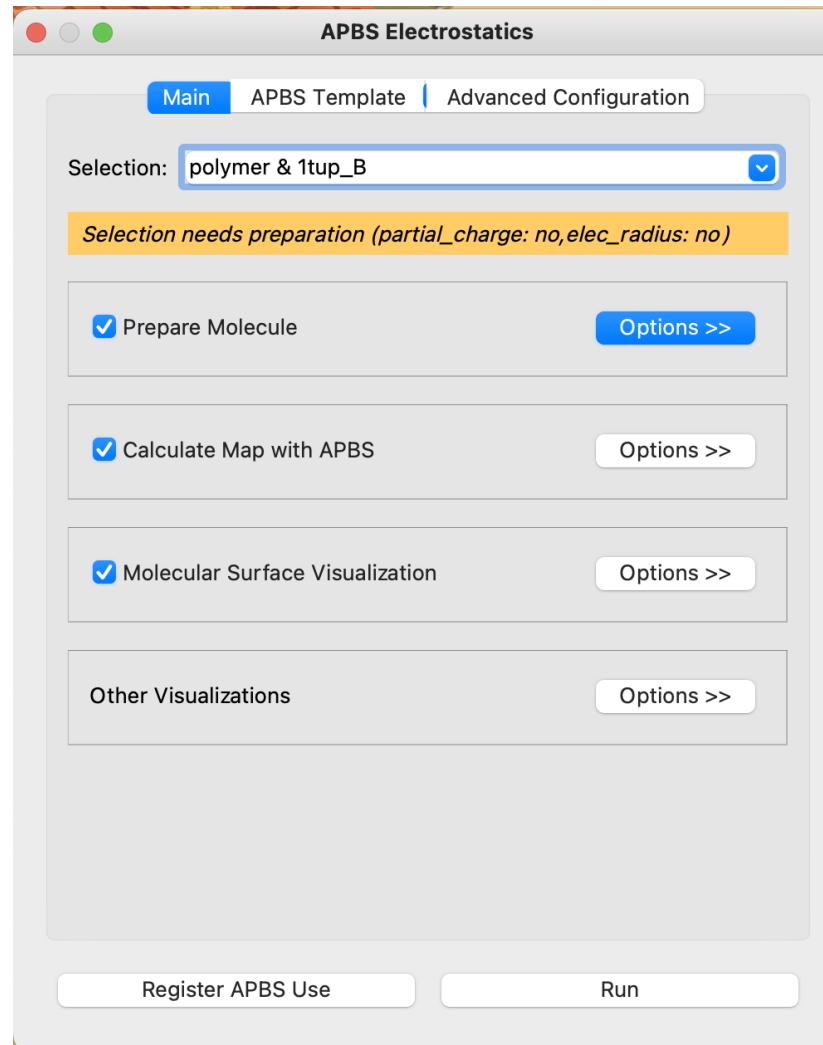
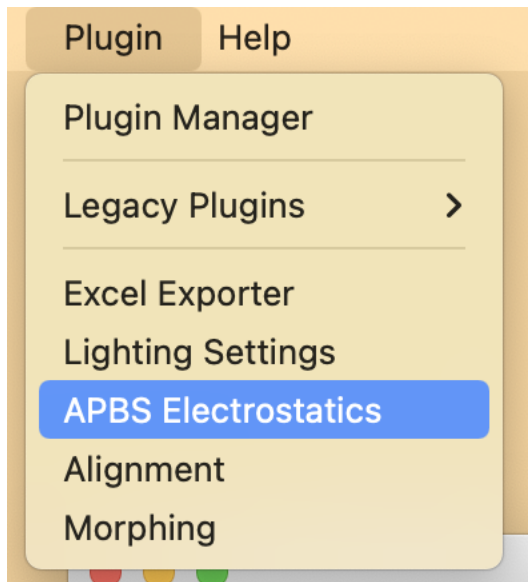
Exercise 5: Showing electrostatics

- Create new individual objects that contain the protein chains A, B and C individually
(use the command `split_chains 1tup`)
- Generate electrostatic potential surfaces quickly:
[A] > generate > vacuum electrostatics > protein contact potential
- Do you see any electronegative or electropositive patches? Where are they located?



Better (more proper) way to generate electrostatics by APBS:

- Plugin > APBS electrostatics > choose your selection > Run (takes some time)
wait till “Finished with Success” popup



If this errors out for you, try going into Prepare Molecule > Options > Method: change to “use formal_charge and vdw”

Exercise 6: Align the three protein chains

- you should have the 3 protein chains in separate objects
- align chains A and C to chain B
[A] > align > to molecule > chain B
- Are the proteins adopting different conformations?

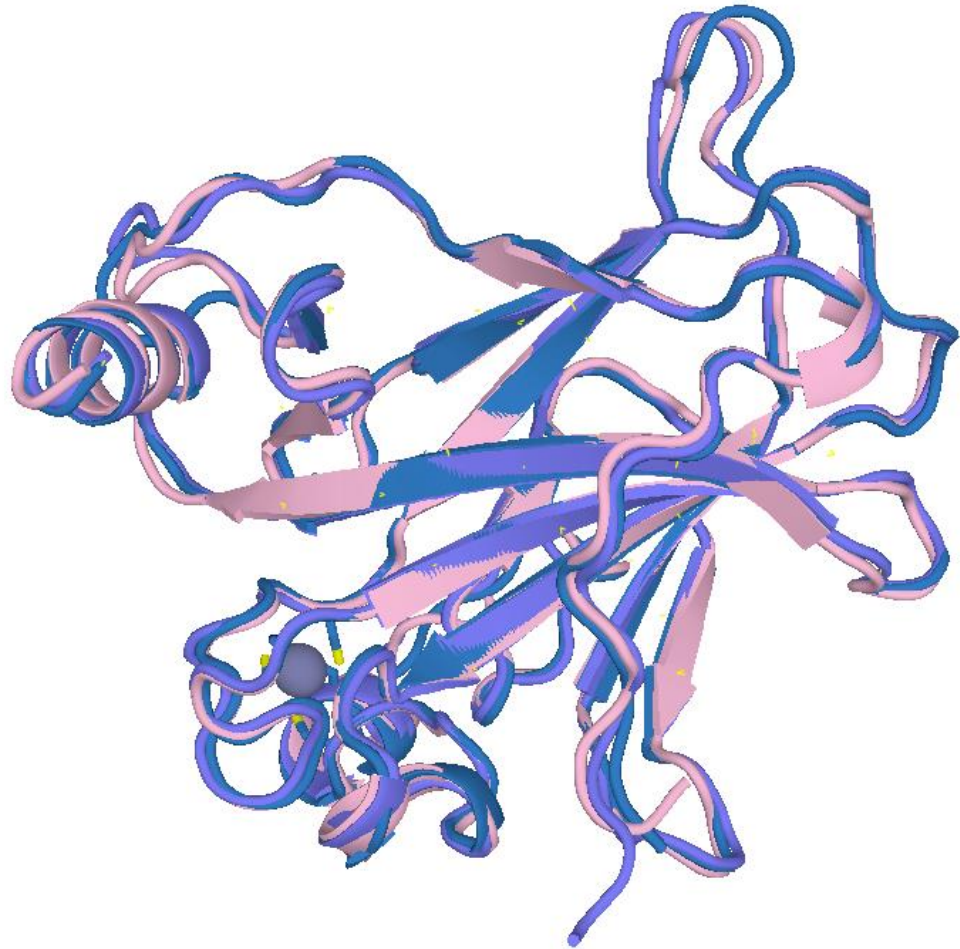
You can align all proteins to a currently selected one
A→Action→Align→All to this

or align proteins one by one
A→Action→Align→To Molecule

Exercise 6: Align the three protein chains

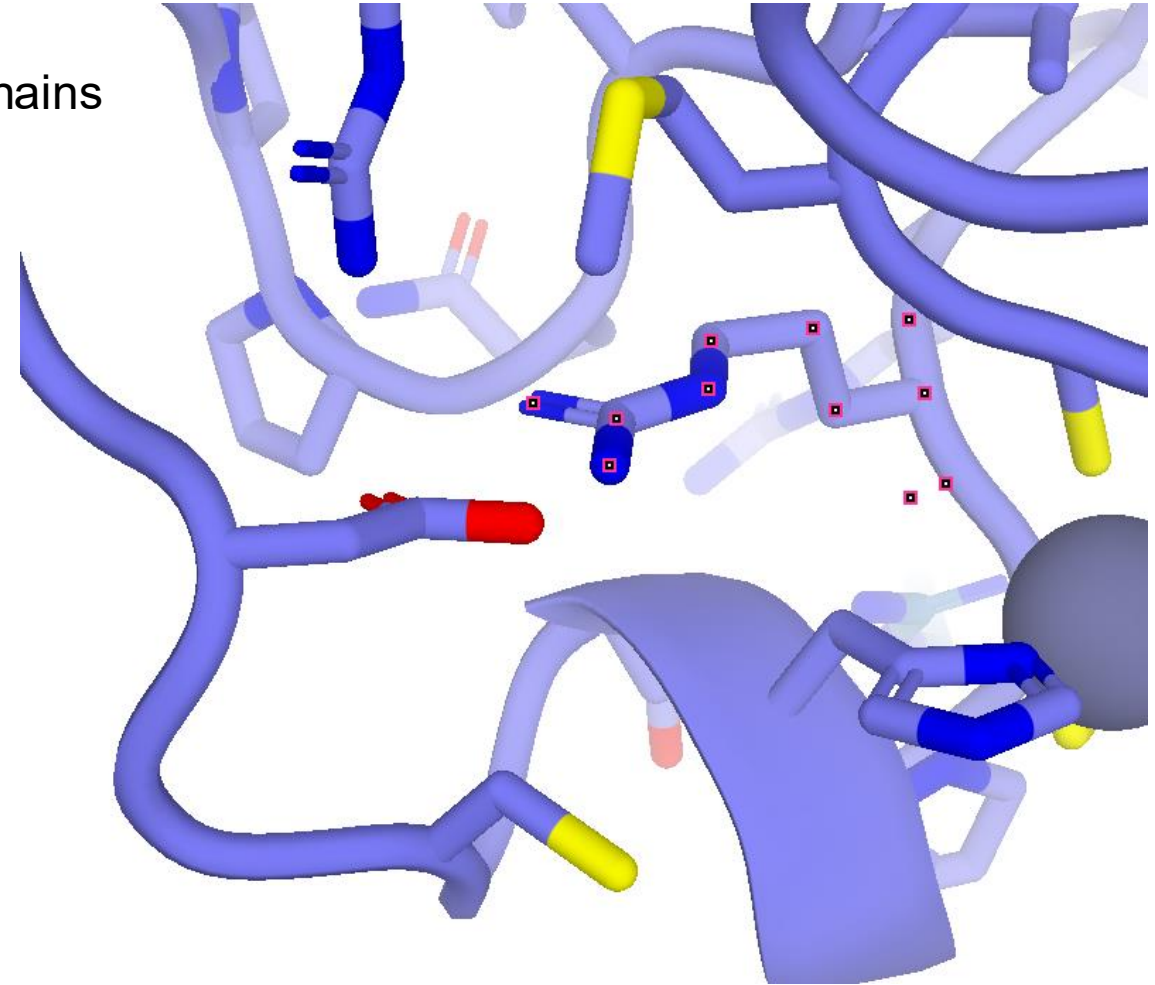
- you should have the 3 protein chains in separate objects
- align chains A and C to chain B
[A] > align > to molecule > chain B
- Are the proteins adopting different conformations?

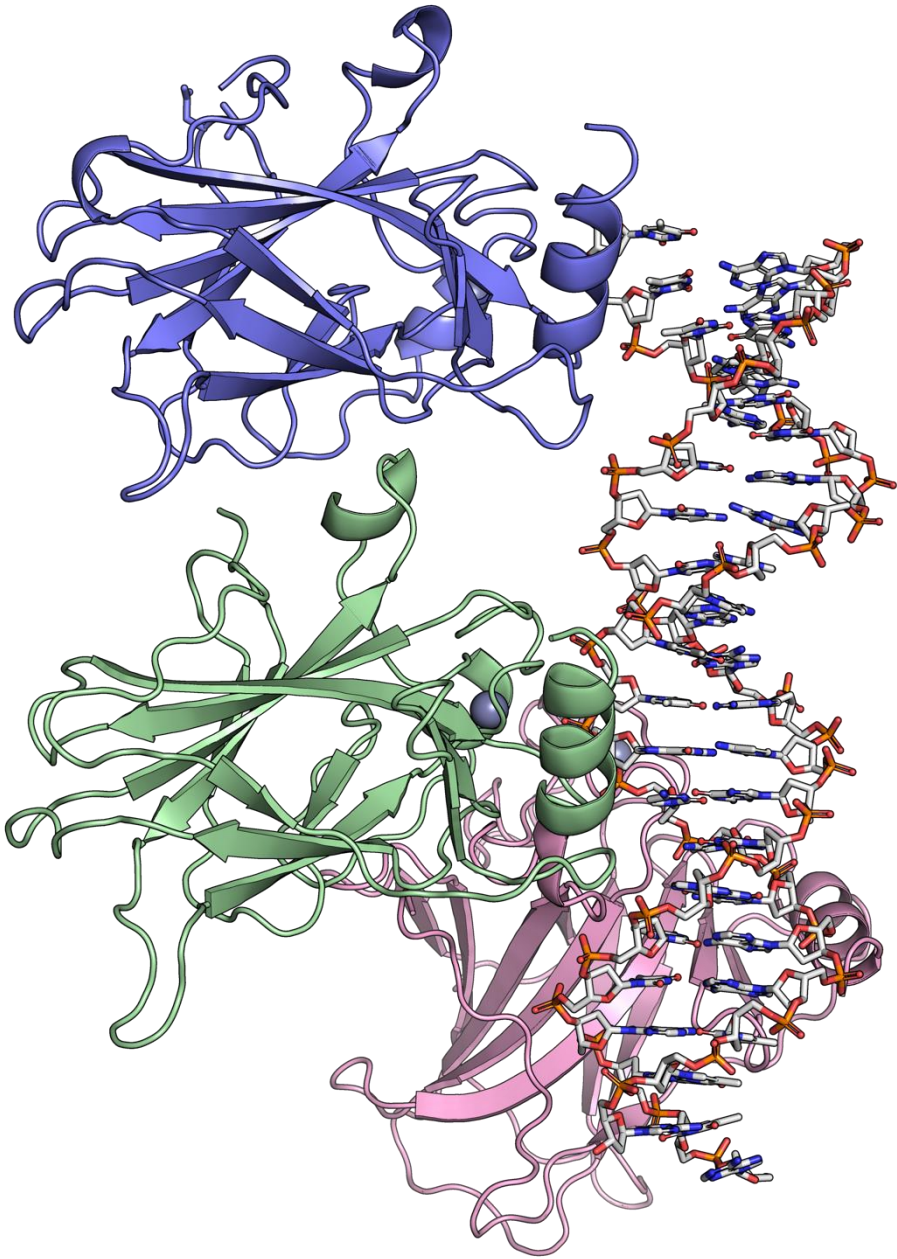
```
ExecutiveRMS: 2 atoms rejected during cycle 5 (RMSD=0.44).  
Executive: RMSD = 0.429 (169 to 169 atoms)  
Executive: object "aln_itup_C_to_itup_B" created.  
PyMOL>set transparency, 0.5  
Setting: transparency set to 0.50000.  
Executive: RMSD = 0.429 (169 to 169 atoms)  
PyMOL>
```



Exercise 7: perform an in silico alanine mutation

- Select R175 in chain A, show and color its sidechain.
- expand the selection to residues within 5 Å and show sidechains
- Go to menu bar Wizard > Mutagenesis
- In the panel on the right, click on 'No Mutation', select ALA.
- Click on the R175 that you want to mutate
- Then click Apply
- What could be an effect of this mutation?





10. Make a figure

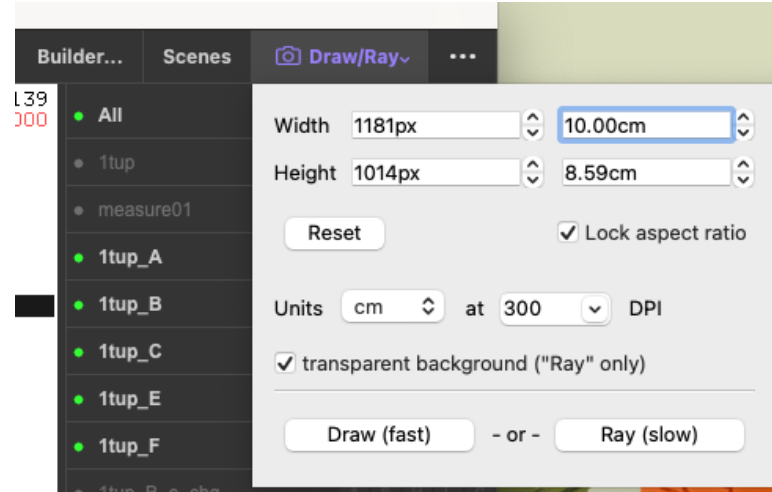
Reset everything (can just open a new window)

1tup

Recolor each protein chain a different color

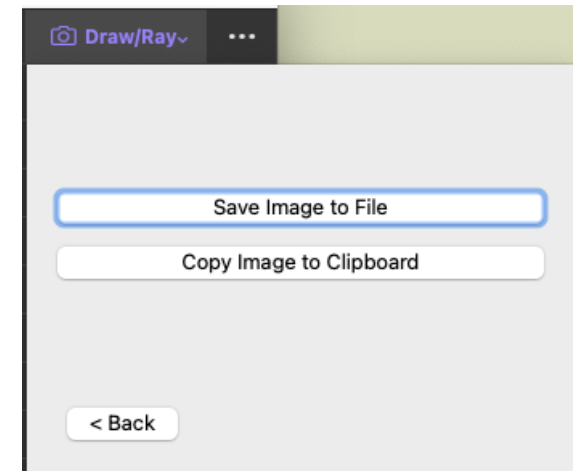
Set DNA chains to be sticks, color by element

Draw/Ray: Ray(slow) > save image as > png to somewhere



Ha An's settings to make it look pretty:
`set spec_count, 0`
`set spec_reflect, 1`

`set ray_shadows, off`
`set ray_trace_mode, 1`



Bonus: look at electron density of an inhibitor

Explore electron density in the crystal structure of COVID-19 main protease in complex with an inhibitor N3 (pdb: 6lu7)

Get pdb... **6lu7**: PDB and 2FoFc map

- Hide waters
- Create a mesh representing the map:
 - Action > mesh > @level 1.0
 - isomesh map, 6lu7_2fofc, 1, 3bep, carve = 2.5
- Color the mesh (e.g. blue > density)
- Color protein chain and inhibitor ([C]->color by chain, [S]->as licorice (sticks)
- Explore electron density for the inhibitor

