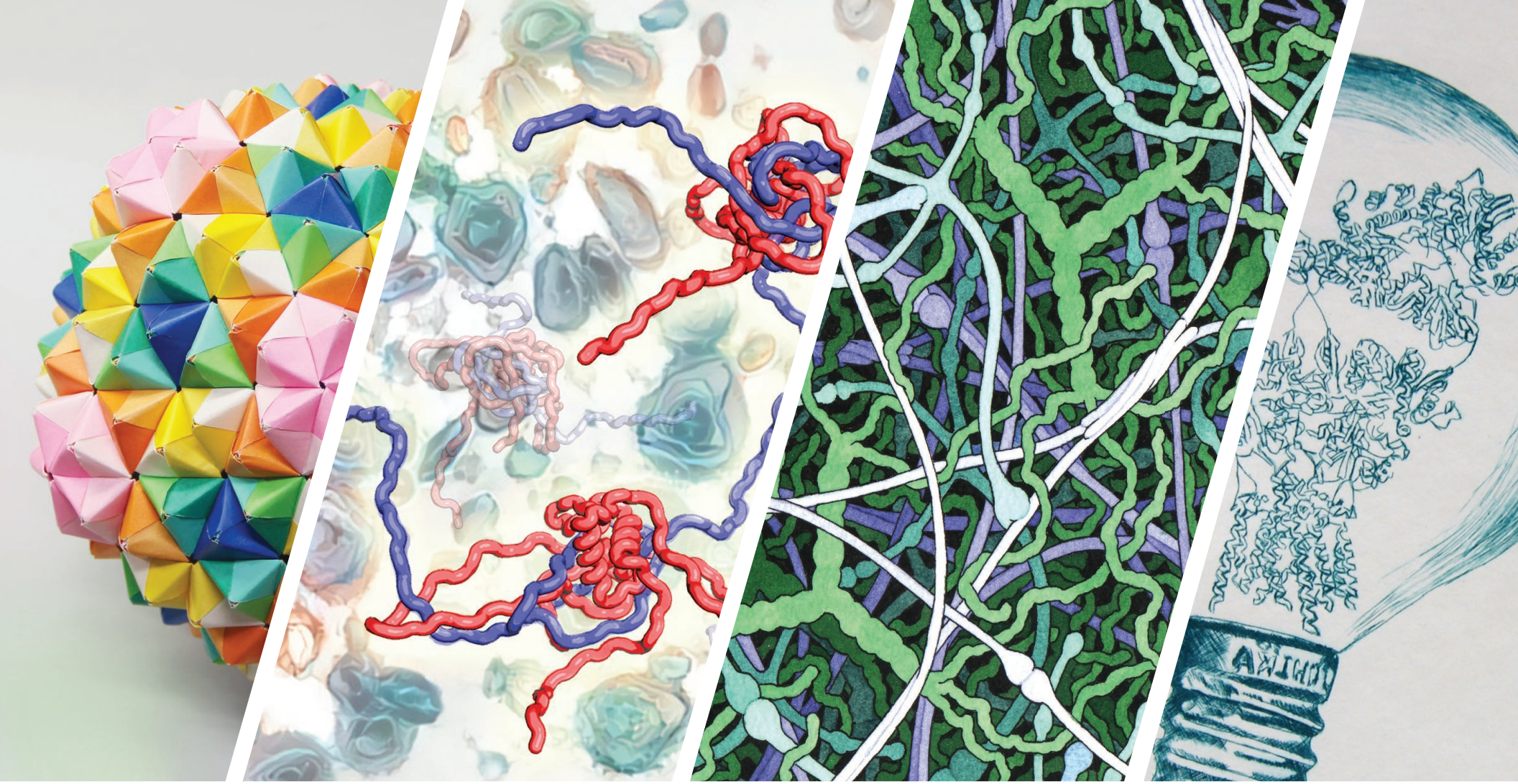
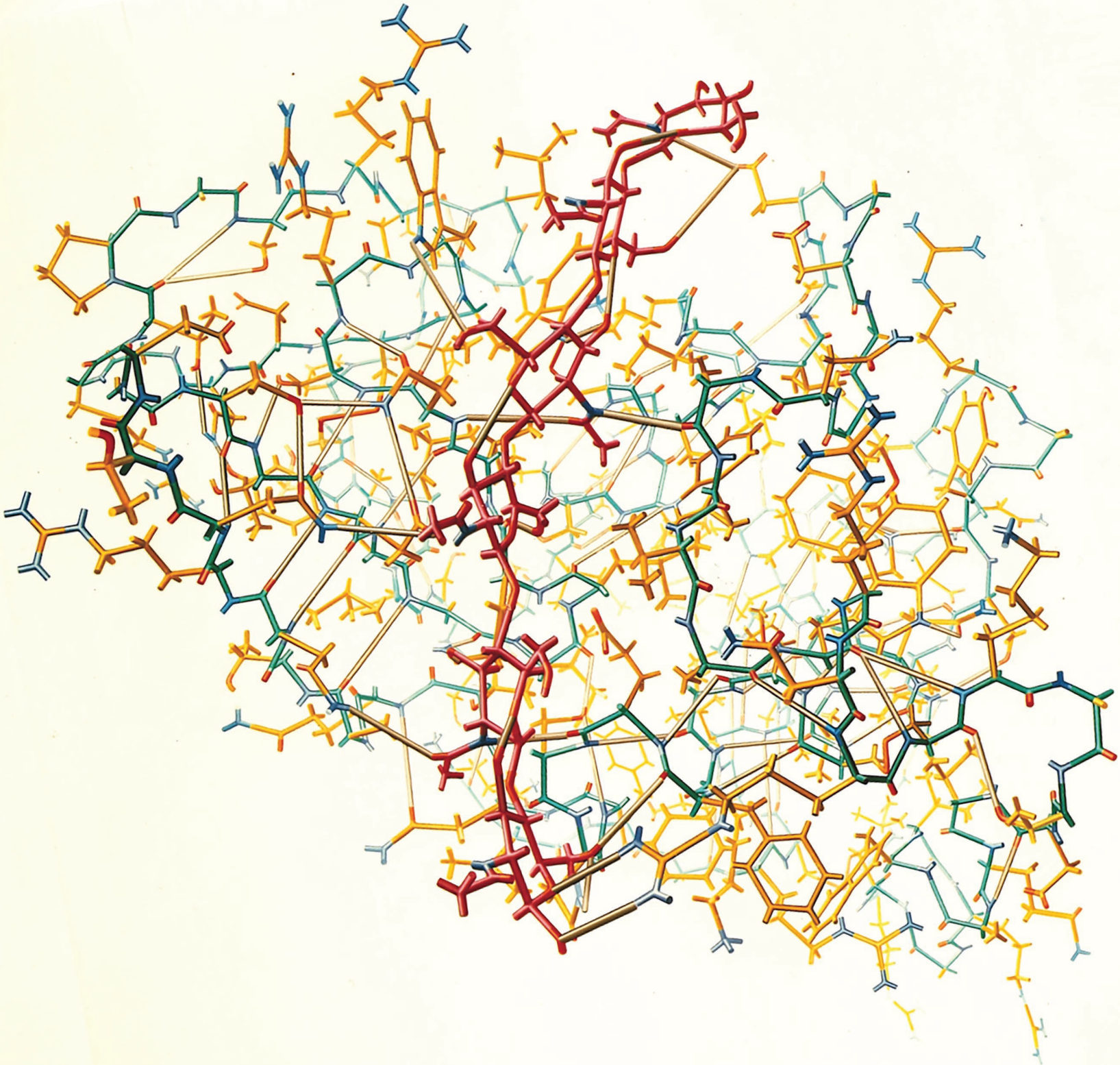


2021 Calendar

Celebrating 50 Years of Protein Data Bank

PROTEIN DATA BANK

50 Years



January 2021

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
27	28	29	30	31	1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31	1	2	3	4	5	6

Lysozyme is a small enzyme that protects us from infections by attacking the protective cell walls of bacteria. It was the first enzyme structure to be determined via X-ray crystallography and one of the historic structures that set the foundation for the PDB archive.

This image was painted by Irving Geis, an artist who helped illuminate the field of structural biology with his iconic images. This particular illustration appeared on the cover of *Scientific American* in 1966.

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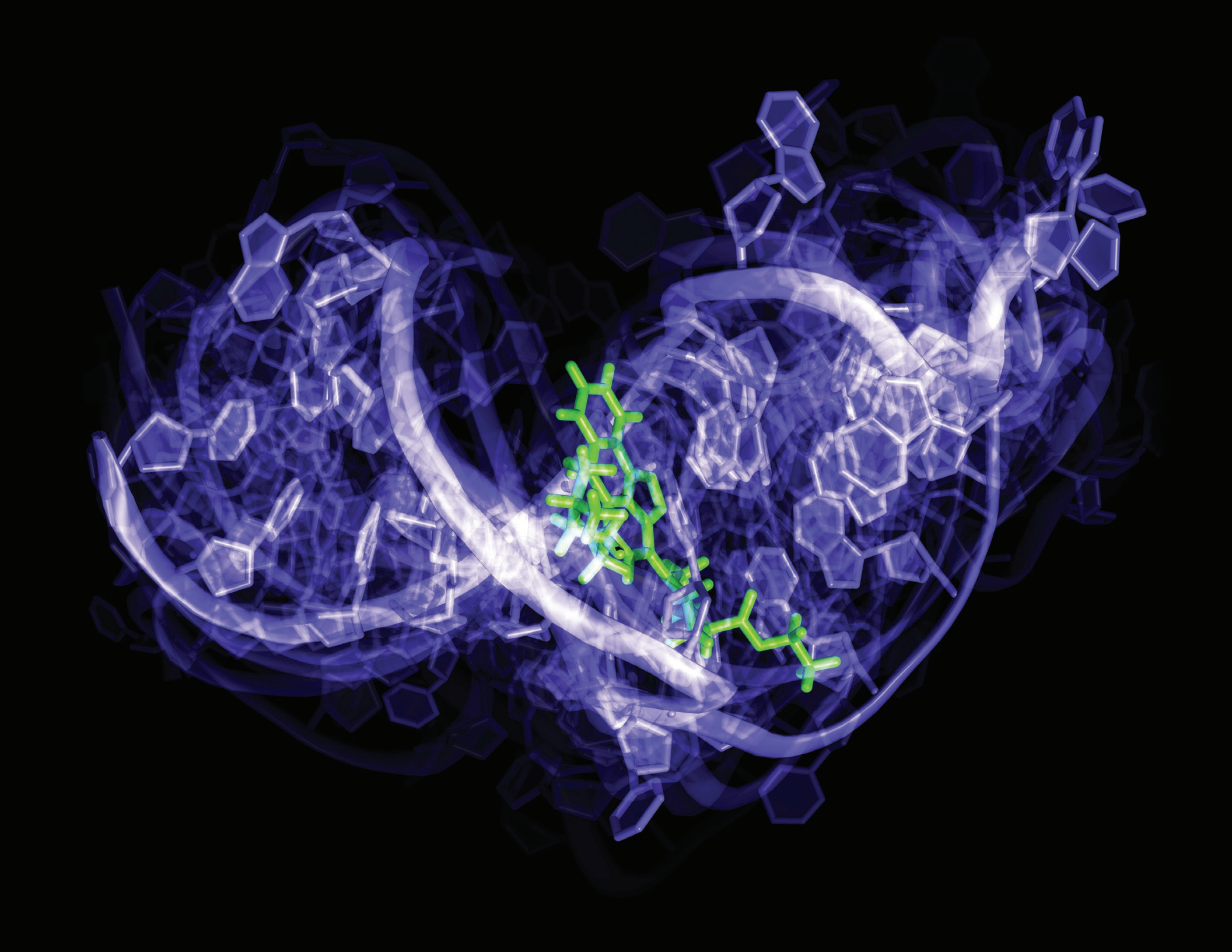
Celebrating PROTEIN DATA BANK Years



February 2021

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
31	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	1	2	3	4	5	6
7	8	9	10	11	12	13

The HIV-1 trans-activation response (TAR) element is an RNA element required for virus replication. TAR adopts a highly dynamic structure. The extent and timescale of the molecular motion is revealed by NMR. Knowledge of the dynamics is aiding the discovery of small molecules that bind TAR as potential therapeutics against HIV.

This image is a long exposure capture of an experimentally derived atomic-resolution ensemble of conformations. The ensemble was generated by using molecular dynamics simulations to generate a library of conformations and then using information about the anisotropy of motions from residual dipolar couplings measured by NMR to guide selection of conformers from the library.

Celebrating
PROTEIN DATA BANK
Years

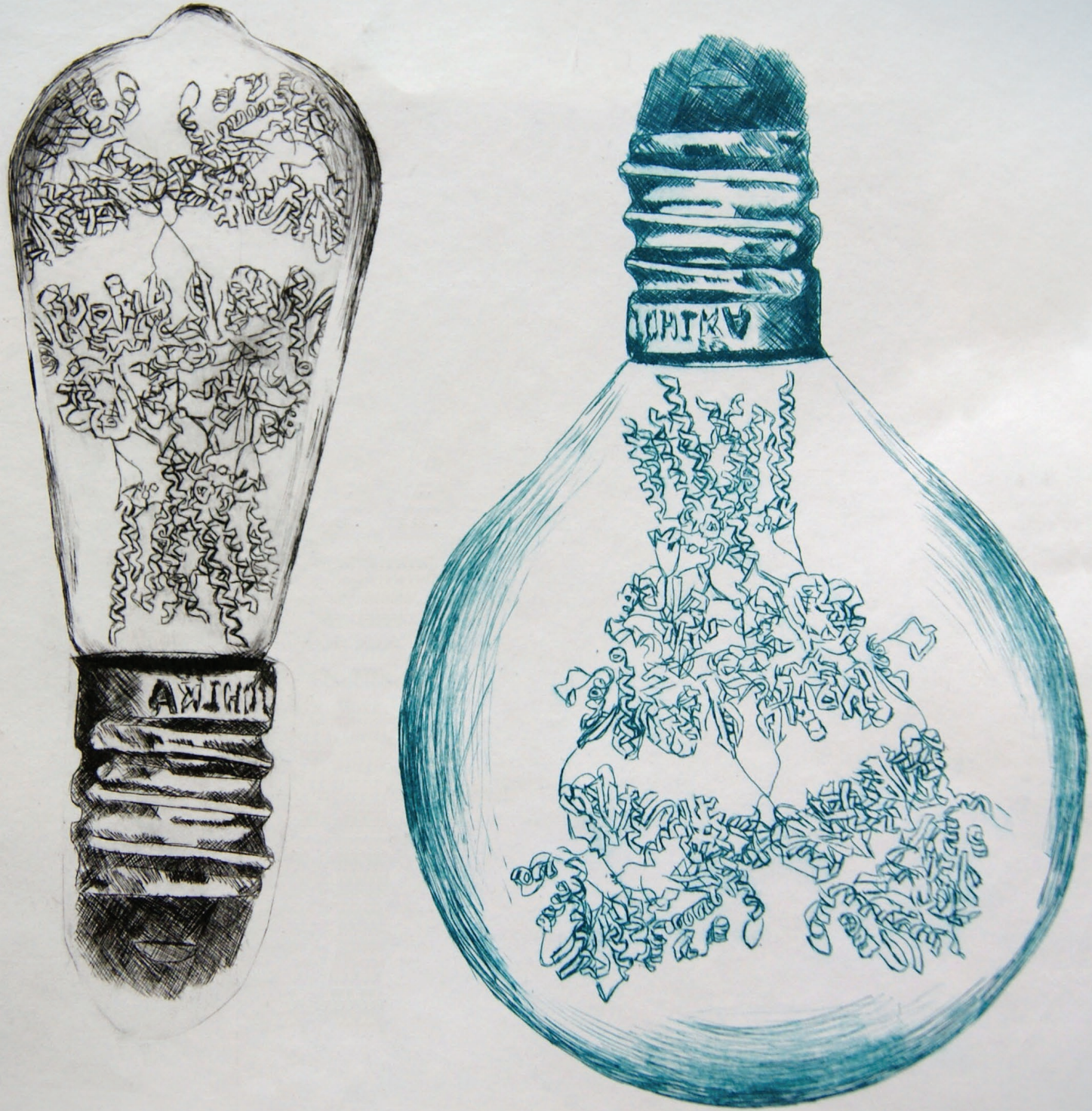
March 2021

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
28	1	2	3	4	5	6
7	8	9	10	11	12	13
14 Daylight Saving Time begins (North America)	15	16	17	18	19	20
21	22	23	24	25	26	27
28 Summer Time begins (Europe)	29	30	31	1	2	3
4	5	6	7	8	9	10

A virus infects living cells and forces them to create many new copies of the pathogen. Viruses are often very simple, composed of a small genome that encodes only a few proteins, including a coat that finds a cell and infects it with the genome. Atomic structures have revealed both the inner workings of viruses and new avenues for the creation of drugs and vaccines to fight them.

Many viruses are icosahedral in form, which can be modeled in 3D using Origami, as shown here.

Celebrating
PROTEIN DATA BANK
Years



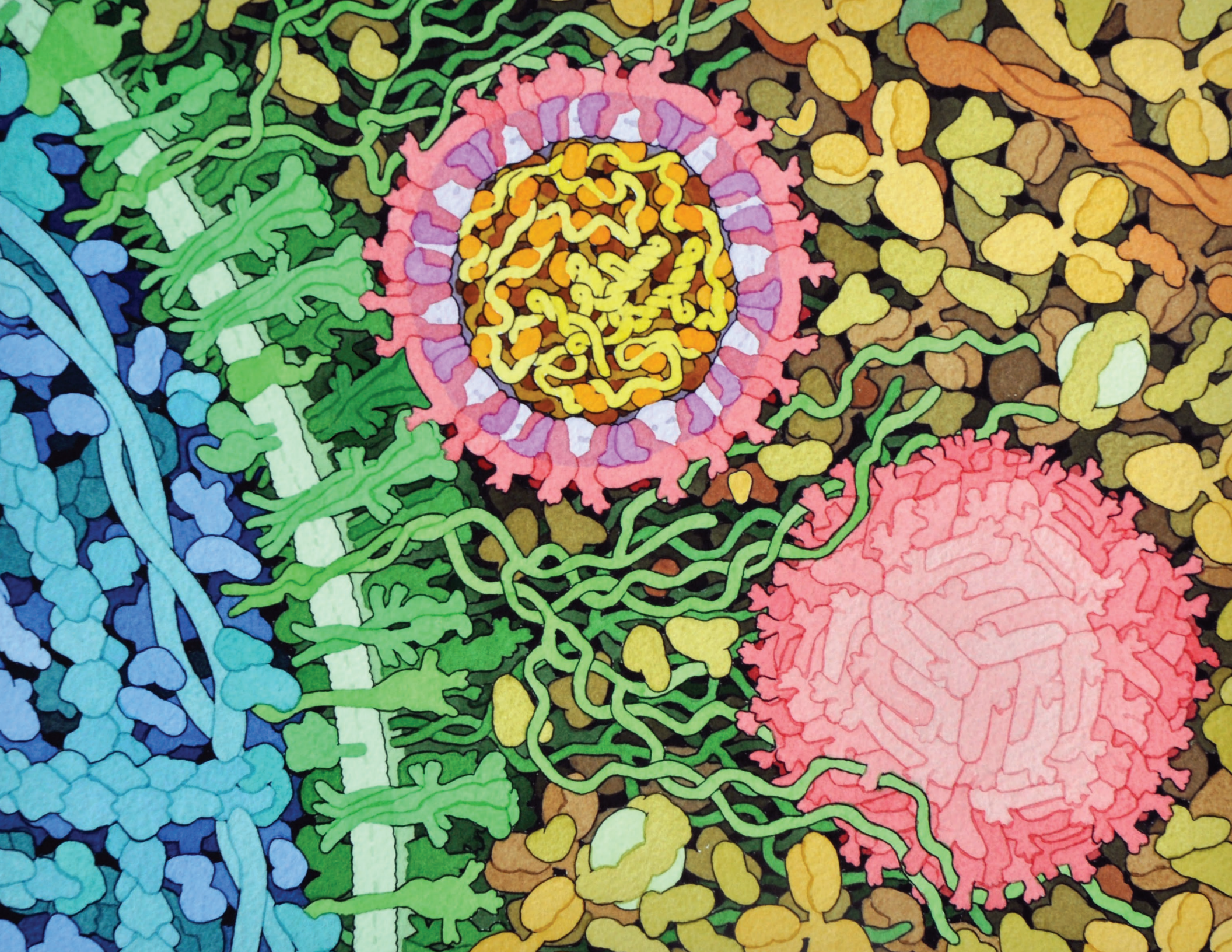
April 2021

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
28	29	30	31	1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22 Earth Day	23	24
25 DNA Day	26	27	28	29	30	1
2	3	4	5	6	7	8

Photosensitive epilepsy is not common, however it still infiltrates people's lives and affects their experiences every day, with seizures triggered by flashing or flickering lights. Glutamate, a type of amino acid, is a major excitatory neurotransmitter that plays a key role in the initiation and spread of seizure activity. This can be controlled by blocking the uptake of glutamate through glutamate receptors, which are, therefore, promising targets for epilepsy therapy.

Here, the light bulb filament is represented by a 3D image of the glutamate receptor protein, highlighting its significance in fighting seizures triggered by light.

Celebrating
PROTEIN DATA BANK
Years



May 2021

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
25	26	27	28	29	30	1
2	3	4 PDB 50 Symposium hosted by ASBMB; Virtual	5 PDB 50 Symposium hosted by ASBMB; Virtual	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31	1	2	3	4	5

Zika virus infects people around the globe. For most, the virus causes a mild illness that is quickly fought off by the immune system. But a connection between Zika infection in pregnant women and birth defects has underscored the need to find ways to fight the disease.

The first atomic-level structure of the Zika virus, shown here in pink, came from the lab of the pioneering structural biologist Michael Rossmann. Structures in the PDB archive help researchers better understand how the virus enters human cells after mosquito-borne or sexual transmission.

Celebrating PROTEIN DATA BANK Years

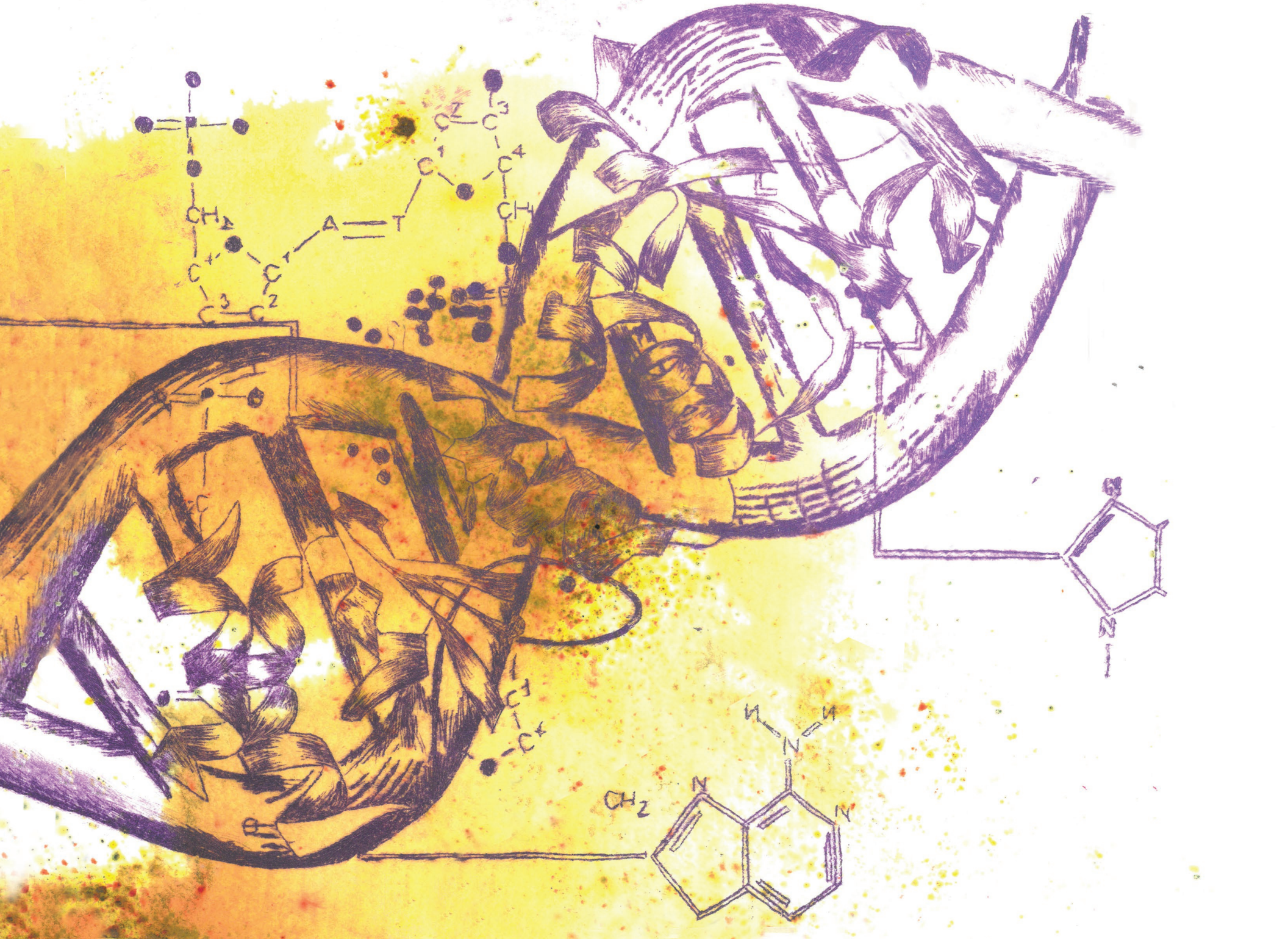
June 2021

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
30	31	1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	1	2	3
4	5	6	7	8	9	10

Cytochrome c is an essential protein in the electron transport chain, a collection of protein-ligand complexes involved in production of cellular energy. It is used to shuttle electrons between complexes using a bound heme molecule, shown in red on this sculpture, to pick up and pass on these electrons.

Cytochrome c was the first structure deposited to the PDB from Asia. The model shown here was created from Japanese wood when the structure was first determined at 4 Å resolution in 1971. The atomic coordinates at a higher resolution of 2.5 Å were deposited to PDB in 1975.

Celebrating
PROTEIN DATA BANK
Years


A
T
CH2
N
N
N
N
H
H
CH2

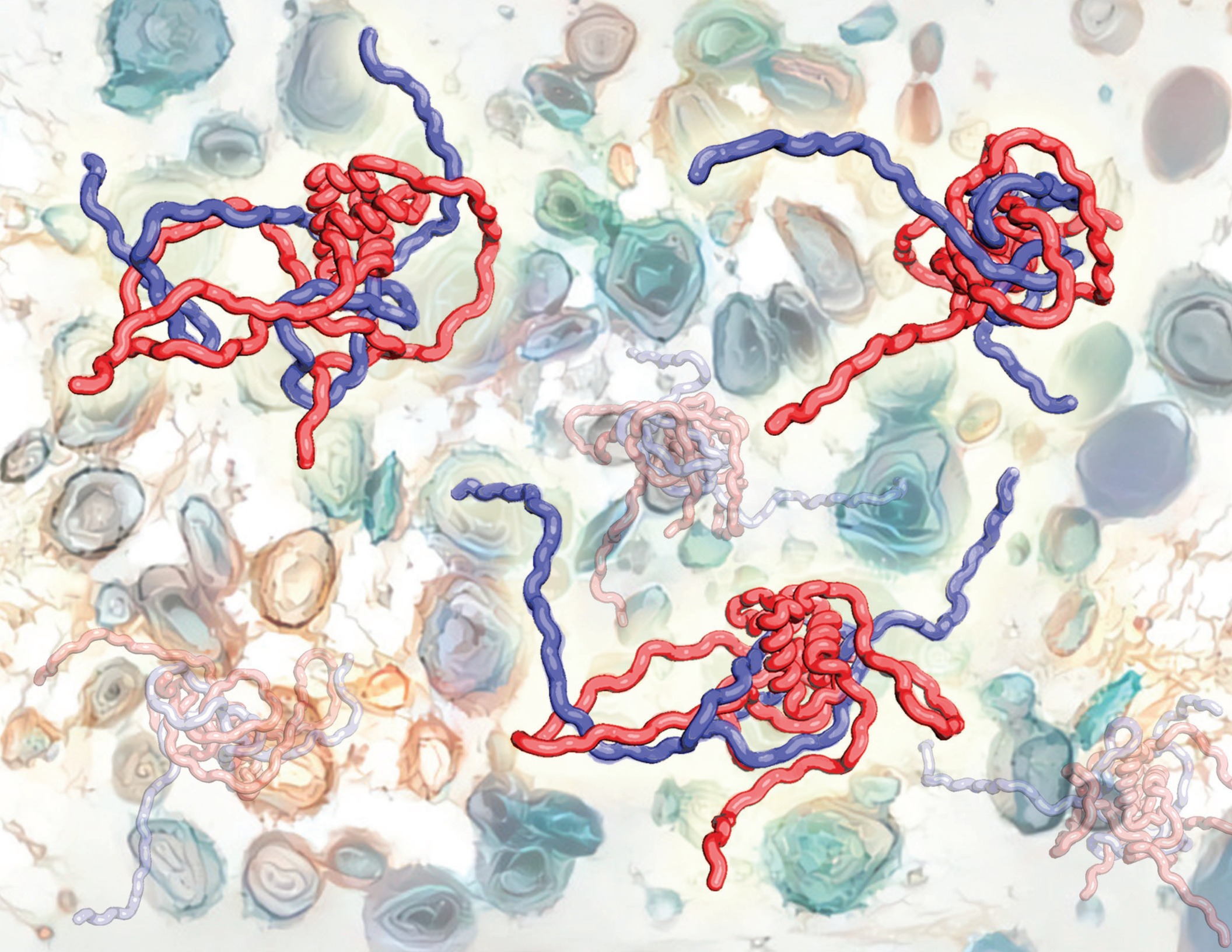
July 2021

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
28	29	30	31	1 wwPDB announced in 2003	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30 ACA Annual Meeting begins in Baltimore, USA	31 PDB50 Transactions Symposium hosted by ACA
1	2	3	4 ACA Annual Meeting ends	5	6	7

Breast cancer is the most common cancer among women. Understanding the complex underlying molecular processes involved in this disease is vital to finding therapeutics to combat this cancer. One important target protein in the quest to understand this disease is BRCA1 (Breast cancer type 1 susceptibility protein), a tumor suppressor protein, found predominantly in breast tissue and responsible for repairing DNA.

Depicted here is the BRCA1 protein interacting with DNA.

Celebrating
PROTEIN DATA BANK
Years

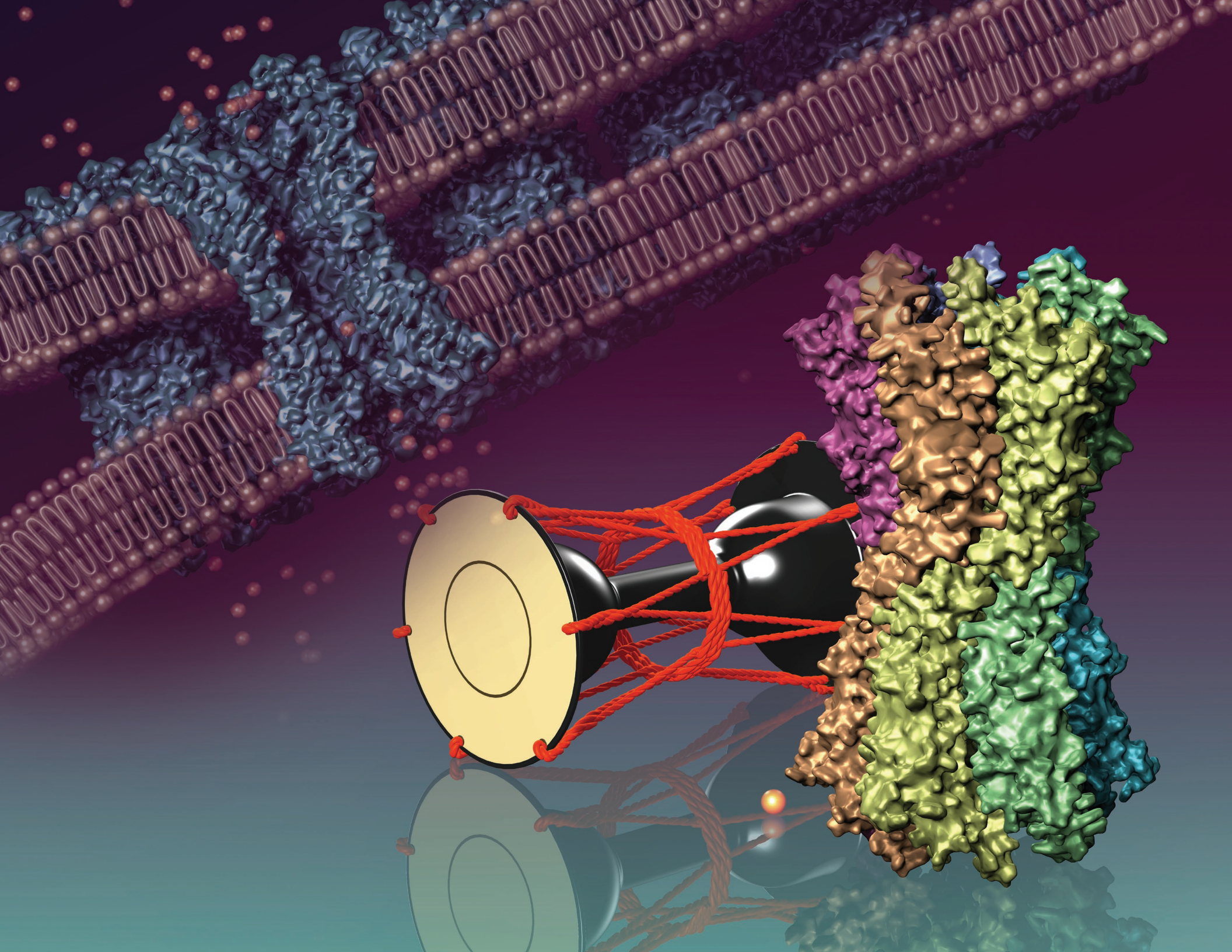


August 2021

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
1	2	3	4 ACA Annual Meeting ends	5	6	7
8	9	10	11	12	13 PDB50 Symposium: *Macromolecular Machines in Biomedicine* (IUCr Satellite) begins	14 IUCr Congress begins in Prague, Czech Republic PDB50 Symposium ends
15	16	17	18	19	20	21
22 IUCr Congress ends	23	24	25	26	27	28
29	30	31	1	2	3	4
5	6	7	8	9	10	11

Protein structure determines the nature of the interactions with other proteins that are important in biological processes. Not all strong protein-protein interactions require well-defined structure, however. The complex between linker histone H1 and Prothymosin exploits highly charged intrinsically-disordered regions (IDRs) and electrostatic interactions averaged over many conformations to form an ultra-high affinity complex with extensive structural fluctuations on extremely fast timescales.

NMR spectroscopy, single-molecule FRET, and molecular dynamics simulations were integrated to characterize the dynamic properties of the disordered complex.



September 2021

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
29	30	31	1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	1	2
3	4	5	6	7	8	9

Gap junctions are tubular arrangements of proteins that connect two cells together, allowing exchange of ions and small molecules. They are essential in neural activity and cell synchronization, especially in cardiac muscle, where they regulate the cardiac cycle.

The gap junction structure shown here consists of twelve connexin-26 proteins and was determined at 3.5 Å resolution by X-ray crystallography. The hourglass-like shape resembles a Japanese hand drum known as a Tsuzumi, also shown in the image.

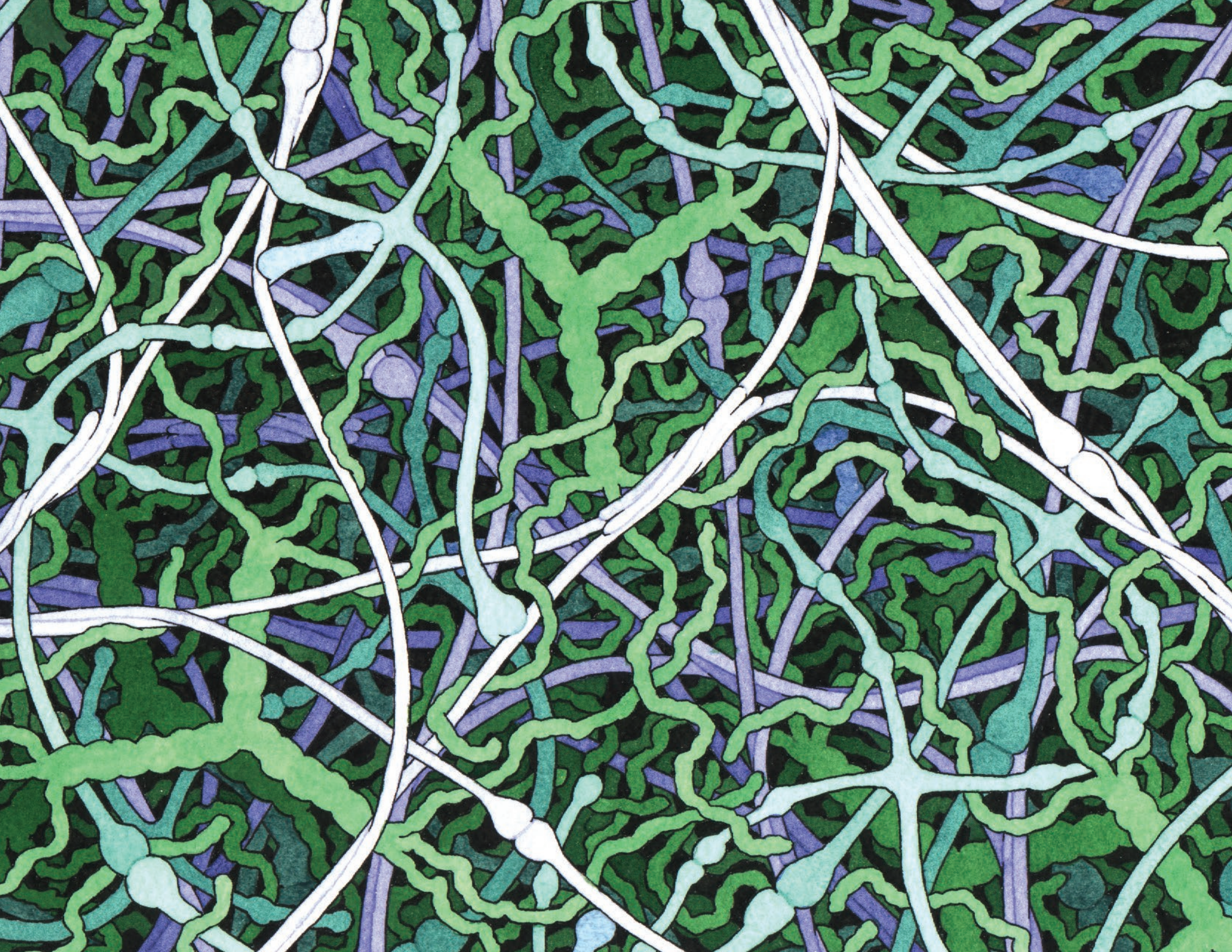
Celebrating
PROTEIN DATA BANK
Years

October 2021

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
26	27	28	29	30	1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20 **PDB announced in 1971** *50 Years of the PDB* Conference hosted by EMBL begins in Heidelberg, Germany	21	22 *50 Years of the PDB* Conference ends	23
24	25	26	27	28	29	30
31 Summer Time ends (Europe)	1	2	3	4	5	6

Oxygen is one of the quintessential molecules of life. Upon entering the lungs, oxygen binds hemoglobin, an iron-rich protein in blood, which carries it to the tissues in the body. Hemoglobin is made up of four polypeptide chains, two alpha and two beta chains, each containing a heme group bound to an iron atom. Oxygen binds reversibly to these iron atoms and is transported through blood. It is the oxygenated state of hemoglobin, called oxyhemoglobin, that gives blood its bright red color, whereas the reduced deoxygenated state is purplish blue in color.

Hemoglobin was one of the very first protein structures to be determined by X-ray crystallography, earning Max Perutz the 1962 Nobel Prize in Chemistry.



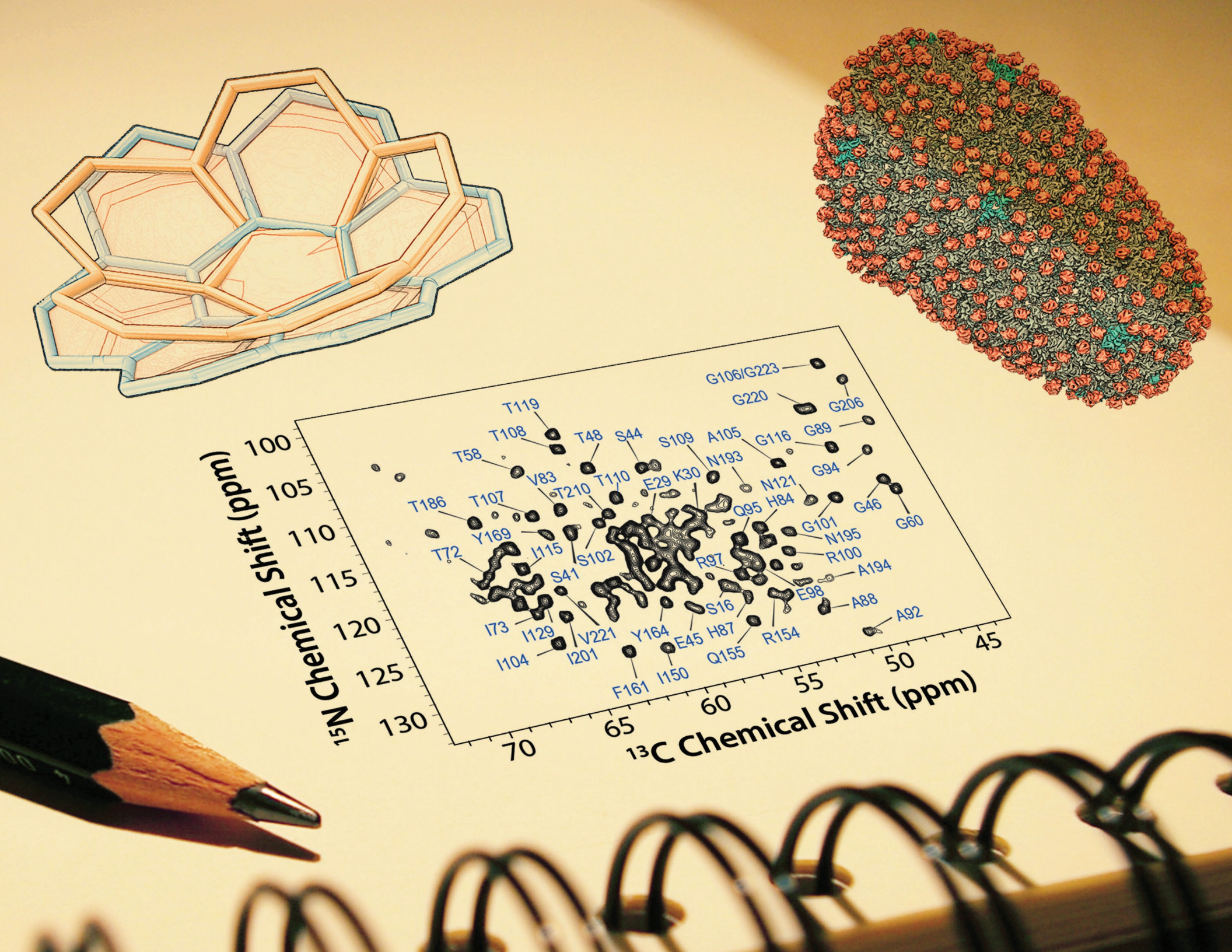
November 2021

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
31	1	2	3	4	5	6
7 Daylight Saving Time ends (North America)	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	1	2	3	4
5	6	7	8	9	10	11

Using triple-helices, collagen forms long ropes and tough sheets that lend structure and elasticity to our bodies. This illustration depicts Type IV collagen-containing basement membrane, which supports skin and many organs. The globular heads at one end of the molecule bind strongly together and at the other end, four collagen molecules associate together through their tails, forming an X-shaped complex. Using these two interactions, type IV collagen forms an extended network (light blue). Two other molecules–cross-shaped laminin (blue-green) and long, snaky proteoglycans (green)–fill in the spaces, forming a dense sheet.

The first atomic resolution structure of a collagen triple-helix was determined in the laboratory of Helen M. Berman, one of the original founders of the PDB archive.

Celebrating
PROTEIN DATA BANK
Years


G106/G223
G220
G206
T119
T108
T48
S44
S109
A105
G116
G89
T58
N193
G94
V83
T110
E29
K30
N121
T186
T107
T210
H84
G46
Q95
G101
G60
Y169
N195
T72
I115
S102
R97
R100
S41
A194
E98
A88
S16
A92
I73
I129
V221
Y164
E45
H87
R154
I104
I201
Q155
F161
I150
100
105
110
115
120
125
130
70
65
60
55
50
45
15N Chemical Shift (ppm)
13C Chemical Shift (ppm)

December 2021

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
28	29	30	1	2	3	4
5	6 17th Conference of the Asian Crystallographic Association (AsCA2021) begins in Malaysia	7	8	9 AsCA2021 ends	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	1
2	3	4	5	6	7	8

A capsid is the protein shell of a virus that protects and conveys the viral genetic material (DNA or RNA). These complex structures can be investigated by integrating multiple structural biology approaches that probe different length scales (commonly referred to as integrative methods). The atomic-resolution structure of HIV-1 capsid protein (CA) tubes was determined by magic-angle-spinning NMR spectroscopy integrated with low resolution cryo-EM data and molecular dynamics simulations. The structure of a single polypeptide chain was calculated using interatomic distance and angle restraints determined by NMR. An atomic-resolution structure of the CA hexamer was derived by integrating the NMR restraints and the low-resolution (8.0 Å) cryo-EM map of the CA hexamer in a tubular assembly. The final structure of a CA tube was determined by data-guided molecular dynamics simulations.

The landmark PDB structure of the HIV capsid shown here and released in 2013 contains a record 2,440,800 explicitly-modeled atoms (PDB ID 3J3Q).

Celebrating
PROTEIN DATA BANK
Years

References and Acknowledgments

This calendar was created as a collaboration between members of the Worldwide Protein Data Bank (wwPDB):

RCSB PDB PROTEIN DATA BANK rcsb.org

RCSB PDB is funded by the National Science Foundation (DBI-1832184), the US Department of Energy (DE-SC0019749), and the National Cancer Institute, National Institute of Allergy and Infectious Diseases, and National Institute of General Medical Sciences of the National Institutes of Health under grant R01GM133198. It is managed by Rutgers, The State University of New Jersey; UC San Diego/San Diego Supercomputing Center; and UC San Francisco.

PDBe Protein Data Bank in Europe pdbe.org

PDBe is supported by European Molecular Biology Laboratory-European Bioinformatics Institute; Wellcome Trust; Biotechnology and Biological Sciences Research Council grants; ELIXIR and Open Targets.

PDBj Protein Data Bank Japan pdbj.org

PDBj is supported by grants from the following: Ministry of Education, Culture, Sports, Science and Technology (MEXT) grants for joint usage and research center assigned to Institute for Protein Research (IPR), Osaka University; National Bioscience Database Center, Japan Science and Technology Agency (JST-NBDC); Japan Agency for Medical Research and Development, Basis for Supporting Innovative Drug Discovery and Life Science Research (AMED-BINDS).

BMRB Biological Magnetic Resonance Data Bank bmrb.io

BMRB is supported by a grant from the National Institute of General Medical Sciences of the National Institutes of Health, R01GM109046.

January

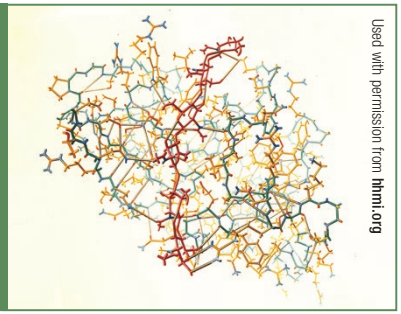


Image credit: Illustration by Irving Geis created for D. Phillips (1966). The three-dimensional structure of an enzyme molecule. *Sci. Am.* **215**:78-90. doi:10.1038/scientificamerican1166-78.

Primary data*: PDB Structure 1lyz
C.C.F. Blake, D.F. Koenig, G.A. Mair, A.C.T. North, D.C. Phillips, V.R. Sarma (1965). Structure of hen egg-white lysozyme. A three dimensional Fourier synthesis at 2 Å resolution. *Nature* **206**:757-61.

February

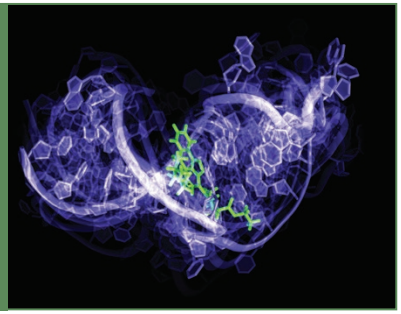


Image credit: Megan Kelly, Laura Ganser, Henry Xu, Hashim Al-Hashimi (Duke)

Additional information: The ensemble of conformers was rendered in PyMol to morph between different conformer members. Inspired by long-exposure photos of ballerinas taken by photographers such as Jesus Chapa-Malacara, we created images that capture the essence of these RNA motions and their choreography. We played our morphing ensembles on a monitor and then took a long-exposure photograph of that movie. This is one such image of an experimentally derived atomic movie of HIV-1 TAR, an important RNA drug target. A single conformation becomes more highly represented in the ensemble when a small molecule ligand binds to it. These images help us to understand RNA dynamics at many timescales as well as RNA-drug interactions.

This research was described in L. Salmon *et al.* (2013) *J. Am. Chem. Soc.* **135**: 5457-5466.

Primary data*: PDB Structure 1anr
F. Aboul-ela, J. Karn, G. Varani (1996). Structure of HIV-1 TAR RNA in the absence of ligands reveals a novel conformation of the trinucleotide bulge. *Nucleic Acids Res* **24**: 3974-3981. doi: 10.1093/nar/24.20.3974

March

Photo credit: Takahiro Kudou, PDBj

Primary data*: PDB Structure 1uf2
A. Nakagawa, N. Miyazaki, J. Taka, H. Naitow, A. Ogawa, Z. Fujimoto, H. Mizuno, T. Higashi, Y. Watanabe, T. Omura, R.H. Cheng, T. Tsukihara (2003). The atomic structure of rice dwarf virus reveals the self-assembly mechanism of component proteins. *Structure* **11**:1227-38. doi: 10.1016/j.str.2003.08.012.

April

Image credit and additional information: In this artwork*, Esther Robson, a 16-year-old student of Leys School (Cambridge, UK), was inspired by structures of Glutamate Receptor 2 bound to potential antiepileptic drugs (PDB IDs 5I1e-h) to create this art piece on epilepsy. The artist explains that the light bulb filament is represented by 3D image of the glutamate receptor protein, therefore highlighting its significance in fighting the seizures triggered by light. The switched off light bulb portrays the inhibition of glutamate receptor by epileptic drugs, removing the danger of inciting seizures imposed by light bulb.

Primary data*: PDB Structure 5I1f
M.V. Yelshanskaya, A.K. Singh, J.M. Sampson, C. Narangoda, M. Kurnikova, A.I. Sobolevsky (2016). Structural bases of noncompetitive inhibition of AMPA-subtype ionotropic glutamate receptors by antiepileptic drugs. *Neuron* **91**:1305-15. doi: 10.1016/j.neuron.2016.08.012

May

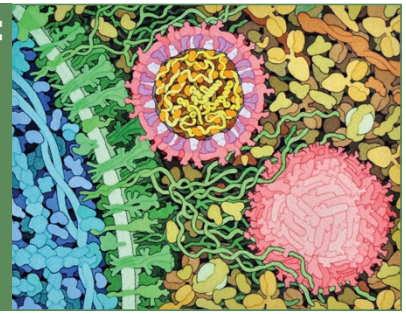


Image credit: David S. Goodsell, RCSB Protein Data Bank. doi: 10.2210/rcsb_pdb/goodsell-gallery-015

Primary data*: PDB Structure 5ire
D. Sirohi, Z. Chen, L. Sun, T. Klose, T.C. Pierson, M.G. Rossmann, R.J. Kuhn (2016). The 3.8 Å resolution cryo-EM structure of Zika virus. *Science* **352**:467-70. doi: 10.1126/science.aaf5316

June

Photo credit: Takahiro Kudou, PDBj. The model is owned by the Institute for Protein Research, Osaka University.

Primary data*: PDB Structure 1cyc
T. Ashida, T. Ueki, T. Tsukihara, A. Sugihara, T. Takano, M. Kakudo (1971). The crystal structure of bonito (Katsuo) ferrocytochrome c at 4 Å resolution. *J Biochem.* **70**:913-24. doi: 10.1093/oxfordjournals.jbchem.a129721

July

Image credit and additional information: Tengyu Zhao, a 14-year-old student from Perse School, Cambridge, UK, created this artwork. She has a keen interest in biology and aspires to become a marine biologist. This dry-point etch print was inspired by the crystal structure of tumor suppressor gene BRCA1. Using DNA as the central piece, she attempts to portray the connections of nucleotide bases of DNA.

Primary data*: PDB Structure 3k16
S.J. Campbell, R.A. Edwards, J.N. Glover (2010). Comparison of the structures and peptide binding specificities of the BRCT domains of MDC1 and BRCA1. *Structure* **18**:167-76. doi: 10.1016/j.str.2009.12.008

August

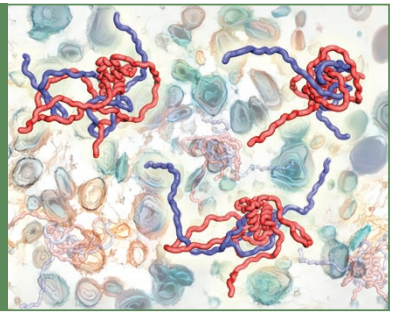


Image credit: Yong Wang, Wei Chen, Birthe Kragelund (U Copenhagen)

Additional information: The image shows snapshots from the ensemble of the complex obtained from a coarse-grained molecular dynamics simulation and rendered using PyMol, where the local charge is shown in blue (for positive) and red (for negative), highlighting the polyelectrolyte properties of the complex. Representative structures of the complex are illustrated to stress the diversity of the ensemble. The image background was made by combining hand-painting and deep learning for artistic style transfer to remind us that even this dynamic protein complex is functional in the environment of a cell, where a multitude of other structures impact its behavior. These cellular structures have been drawn to resemble peaks in an artistic NMR spectrum to emphasize the importance of NMR to biology.

Primary data*: BMRB entries 27216, 27215
A. Borgia, M.B. Borgia, K. Bugge, V.M. Kissling, P.O. Heidarsson, C.B. Fernandes, A. Sottini A, A. Soranno, K.J. Buholzer, D. Nettels, B.B. Kragelund, R.B. Best, B. Schuler (2018). Extreme disorder in an ultrahigh-affinity protein complex. *Nature* **555**:61-6. doi: 10.1038/nature25762.

September

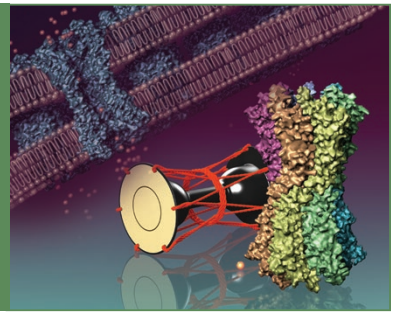


Image credit: PDBj

Primary data*: PDB Structure 2zw3
S. Maeda, S. Nakagawa, M. Suga, E. Yamashita, A. Oshima, Y. Fujiyoshi, T. Tsukihara (2009). Structure of the connexin 26 gap junction channel at 3.5 Å resolution. *Nature* **458**:597-602. doi: 10.1038/nature07869

October

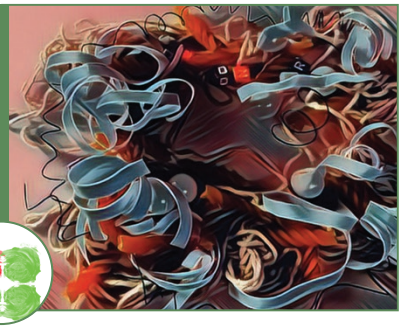


Image credit and additional information: Three classes of 12-year-old students of Thomas Gainsborough School (Sudbury, UK) studied the role of blood and hemoglobin in animals. This artwork* is from Charlie Coot who studied the effects of low density hemoglobin, namely anemia, and chose hemoglobin of white tailed deer to create this artwork. Inspired by the photograms of artist Man Ray, Charlie created this photogram using paper curls, pasta and beads.

Primary data*: PDB Structure 1hds
R.L. Girling RL, T.E. Houston, W.C. Schmidt Jr, E.L. Amma (1980). Macromolecular structure refinement by restrained least-squares and interactive graphics as applied to sickling deer type III hemoglobin. *Acta Cryst.* **A36**:43-50 doi: 10.1107/S0567739480000083

November

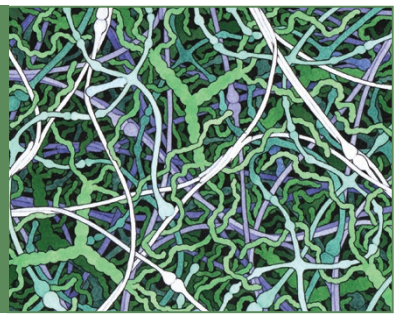


Image credit: David S. Goodsell doi:10.2210/rcsb_pdb/mom_2000_4

Primary data*: PDB Structure 1cag
J. Bella, M. Eaton, B. Brodsky, H.M. Berman (1994). Crystal and molecular structure of a collagen-like peptide at 1.9 Å resolution. *Science* **266**:75-81. doi: 10.1126/science.7695699

December

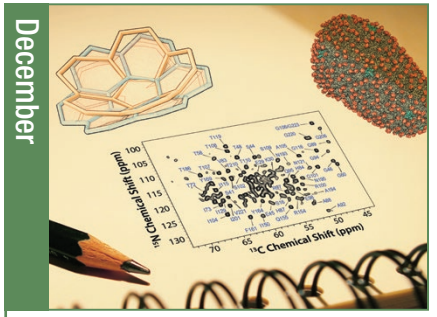


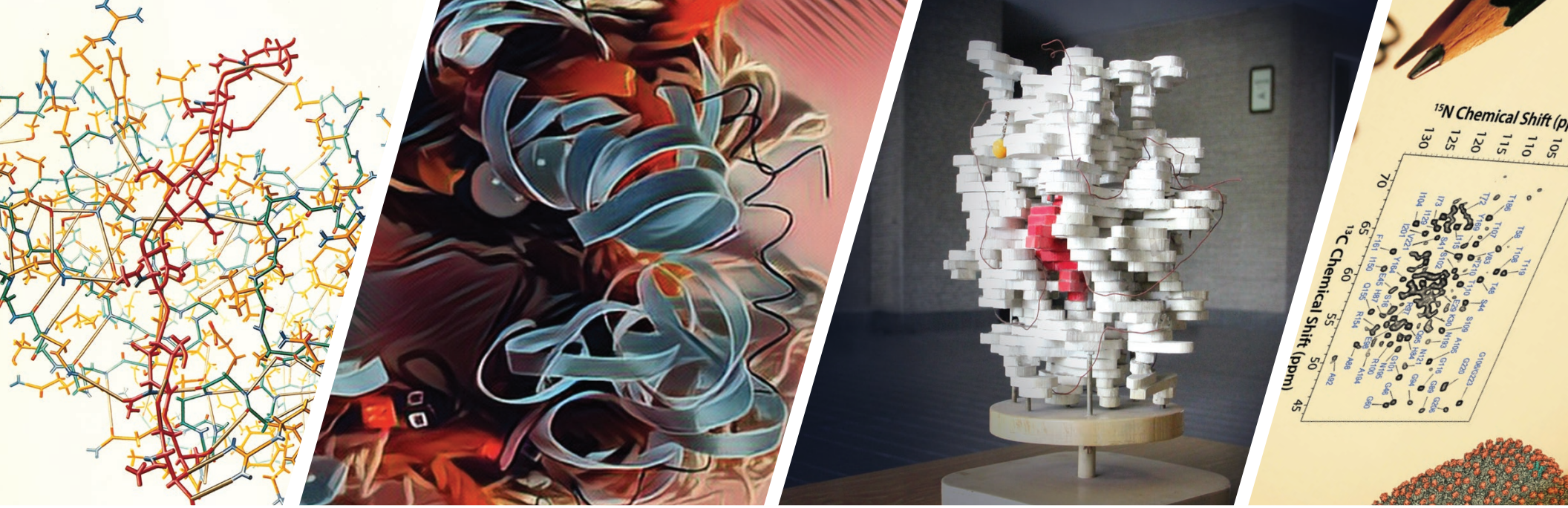
Image credit: Tatyana Polenova, Juan Perilla (U Delaware), Angela Gronenborn (U Pittsburgh)

Additional Information: The majority of side chain conformations could be experimentally defined from MAS NMR restraints. Moreover, the integration of MAS-NMR and data-guided MD with rigorous model-free statistical analysis permitted assessment of distinct conformational clusters in these regions, denoting their relative populations. This structural diversity underlies the unprecedented structural plasticity of the capsid, exploited in HIV-1 function. The structure provides important guidance for the design of novel capsid inhibitors. The image was rendered in VMD and composed in Photoshop, and represents the long hours needed in sketching the experiments required to derive the structure.

Primary data*: PDB Structures 3j3q, 3j3y
G. Zhao, J.R. Perilla, E.L. Yufenyuy, X. Meng X, B. Chen, J. Ning, J. Ahn, A.M Gronenborn, K. Schulten, C. Aiken, P. Zhang (2013). Mature HIV-1 capsid structure by cryo-electron microscopy and all-atom molecular dynamics. *Nature* **497**:643-6. doi: 10.1038/nature12162

* 3D structural data were the primary inspiration for each of the illustrations in this calendar. The data were enriched by integrating additional scientific information to create contextual visualizations, or by creating visual metaphors based on intrinsic qualities of the 3D structure. In some cases three-dimensional objects reflecting the overall shape of the protein were created and photographed. To explore any of the PDB structures used as inspiration for these illustrations in 3D, choose one of the wwPDB member pages–**rcsb.org**, **pdbe.org**, or **pdbj.org**–and enter the PDB structure ID into the *Search* interface. To explore the BMRB entries, enter the BMRB entry ID on **bmrb.io**.

These artworks were created as part of the PDB Art project, a collaboration between Protein Data Bank in Europe (PDBe), The Art Society CANTAB, and The Art Society GRANTA, who together work with local school students and art departments to support the creation of artworks inspired by the molecules of life. Find out more at **PDBe.org/art**.



2021 marks the 50th anniversary of the PDB archive

In the late 1950s, scientists began to decipher the 3D shapes of proteins at the level of individual atoms. The implications of these new structures for science inspired the new field of Structural Biology. Imagining the potential research enabled by archiving and sharing data from these experiments moved the scientific community to action.

In June 1971, a symposium on *Structure and Function of Proteins at the Three Dimensional Level* was held at Cold Spring Harbor Laboratory. With its lively conversations, debates, and planning for the future, that meeting defined the beginning of the PDB as an archive for the experimentally-determined 3D structures of biological macromolecules. Later that year, the Protein Data Bank archive was established as the first open-access, digital resource for biology.[1]

As PDB enters 2021, the archive contains and supports online access to ~170,000 of biomacromolecular structures determined via macromolecular crystallography, Nuclear Magnetic Resonance spectroscopy, and 3D Electron Microscopy by researchers from around the world. These structures help researchers understand fundamental biology, biomedicine, biological energy, and biotechnology, and other research pertaining to global prosperity and environmental sustainability.

WORLDWIDE PDB PROTEIN DATA BANK

wwPDB.org

The PDB archive is managed by the Worldwide Protein Data Bank (wwPDB), a consortium of organizations that host deposition, annotation, and distribution centers for PDB data and collaborate on a variety of projects and outreach efforts.[2,3]

Worldwide Protein Data Bank Foundation

foundation.wwpdb.org

The Worldwide Protein Data Bank Foundation supports the outreach activities of the wwPDB, including symposia and events that will be held in 2021. Individual and institutional donations are critical for future wwPDB outreach efforts.

1. Protein Data Bank. Crystallography: Protein Data Bank. (1971). *Nature New Biology* **233**, 223–223. doi:10.1038/newbio233223b0

2. H.M. Berman, K. Henrick, H. Nakamura (2003). Announcing the worldwide Protein Data Bank. *Nature Structural Biology* **10** (12): 980.

3. wwPDB consortium. (2019) Protein Data Bank: the single global archive for 3D macromolecular structure data. *Nucleic Acids Res*, **47**: D520-D528. doi: 10.1093/nar/gky949.