DE NOVO PROTEIN DESIGN

Image: Evan Ingersoll & Gaël McGill (Digizyme)

Proteins carry out all of the important jobs in living things.

Image: Evan Ingersoll & Gaël McGill (Digizyme)

Proteins carry out all of the important jobs in living things.

They evolved to solve challenges that arose during evolution,

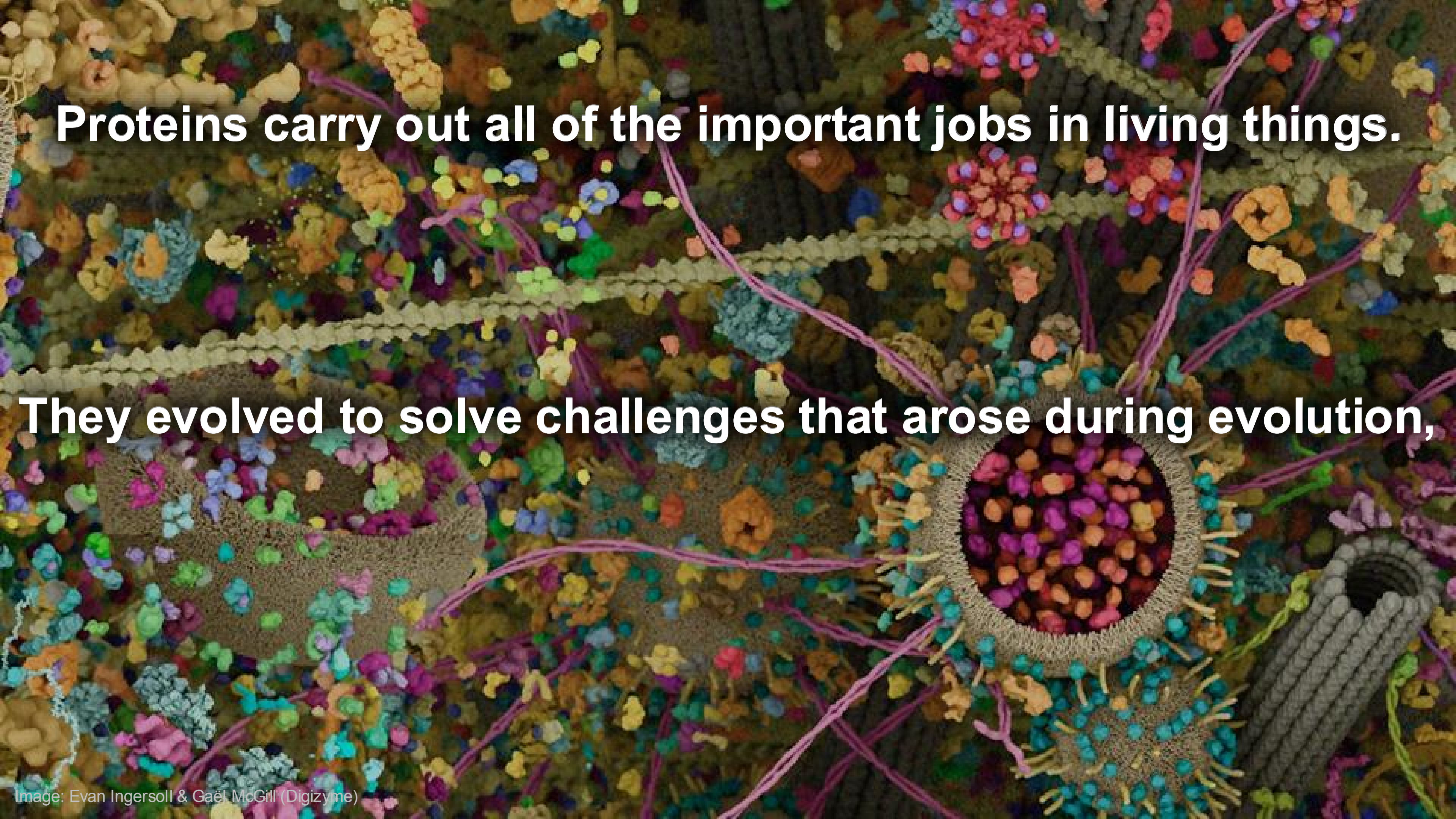


Image: Evan Ingersoll & Gaël McGill (Digizyme)

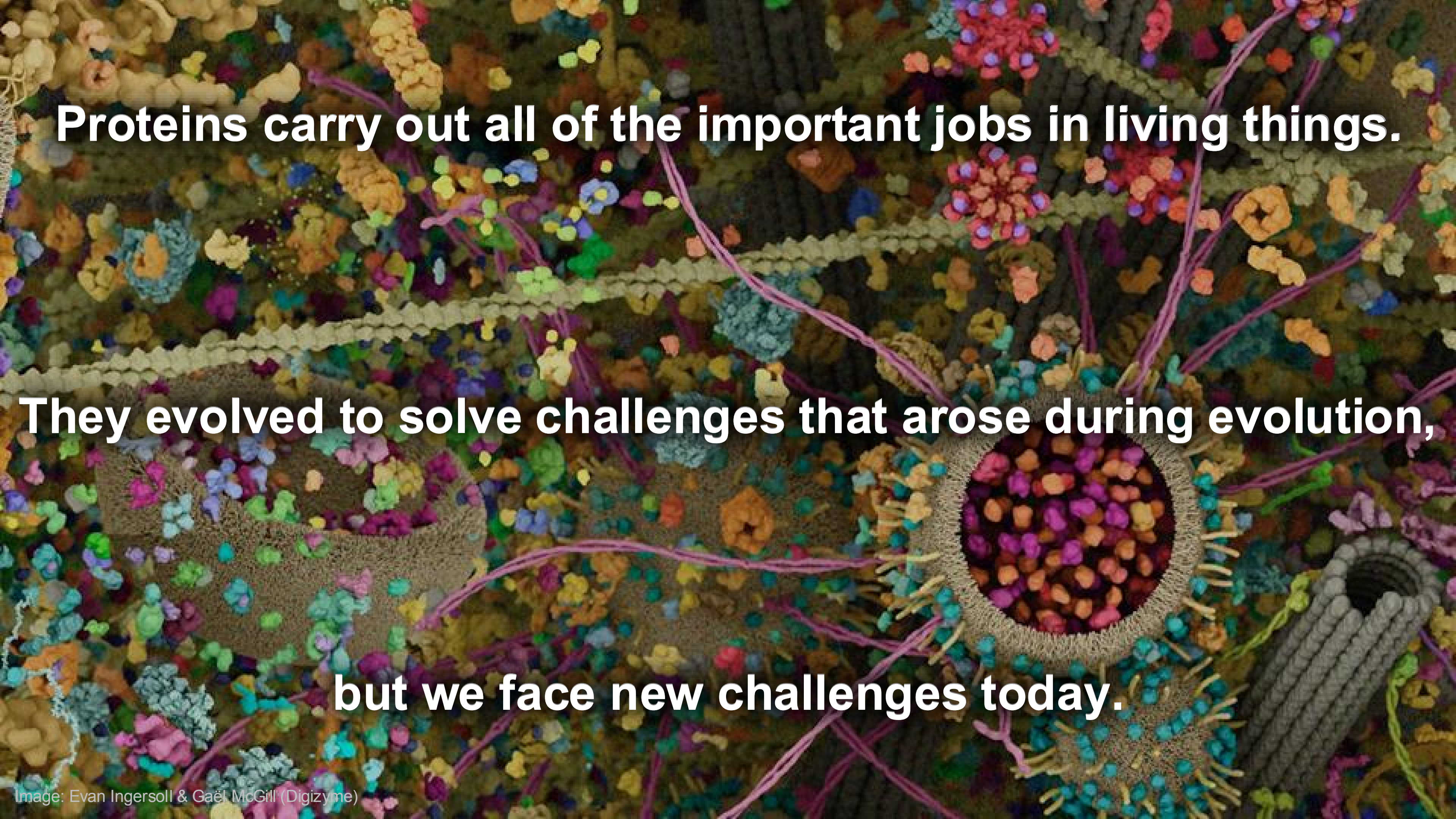
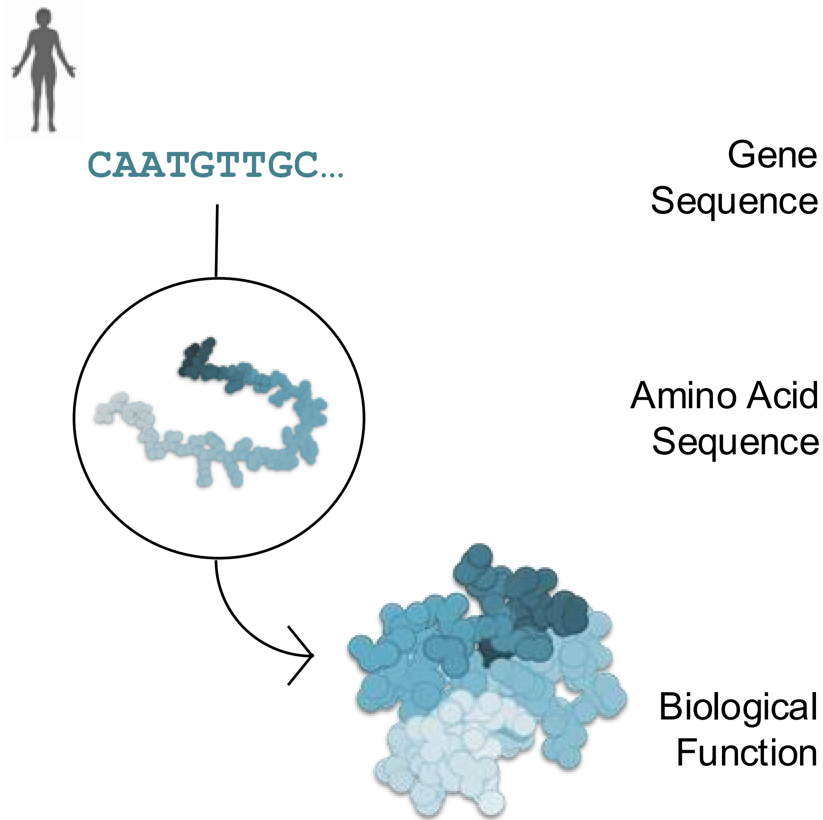
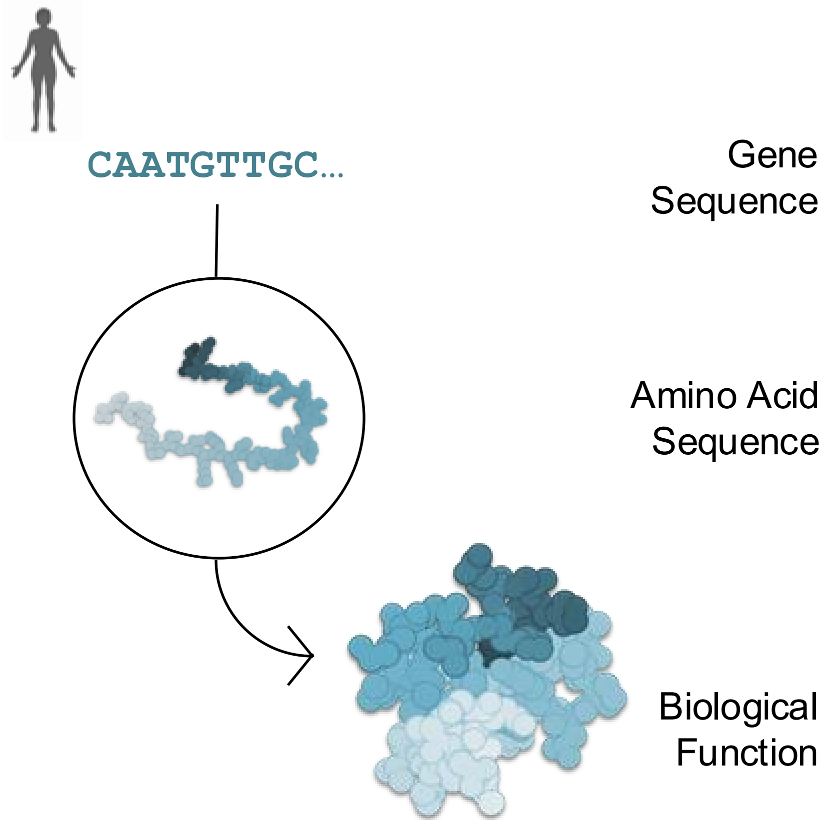


Image: Evan Ingersoll & Gaël McGill (Digizyme)

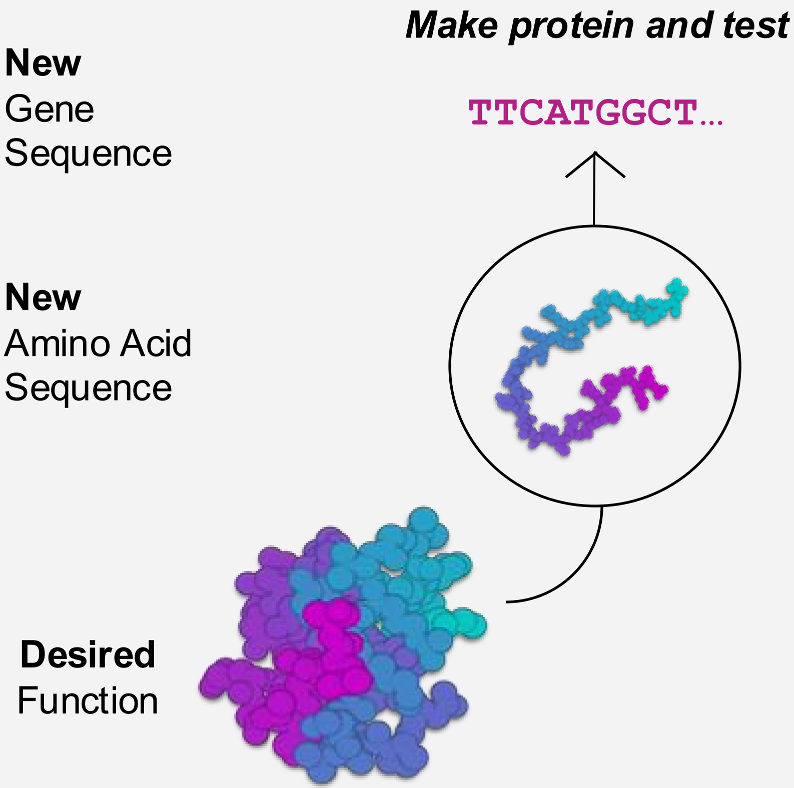
Biology


CAATGTTGC...
Gene Sequence
Amino Acid Sequence
Biological Function

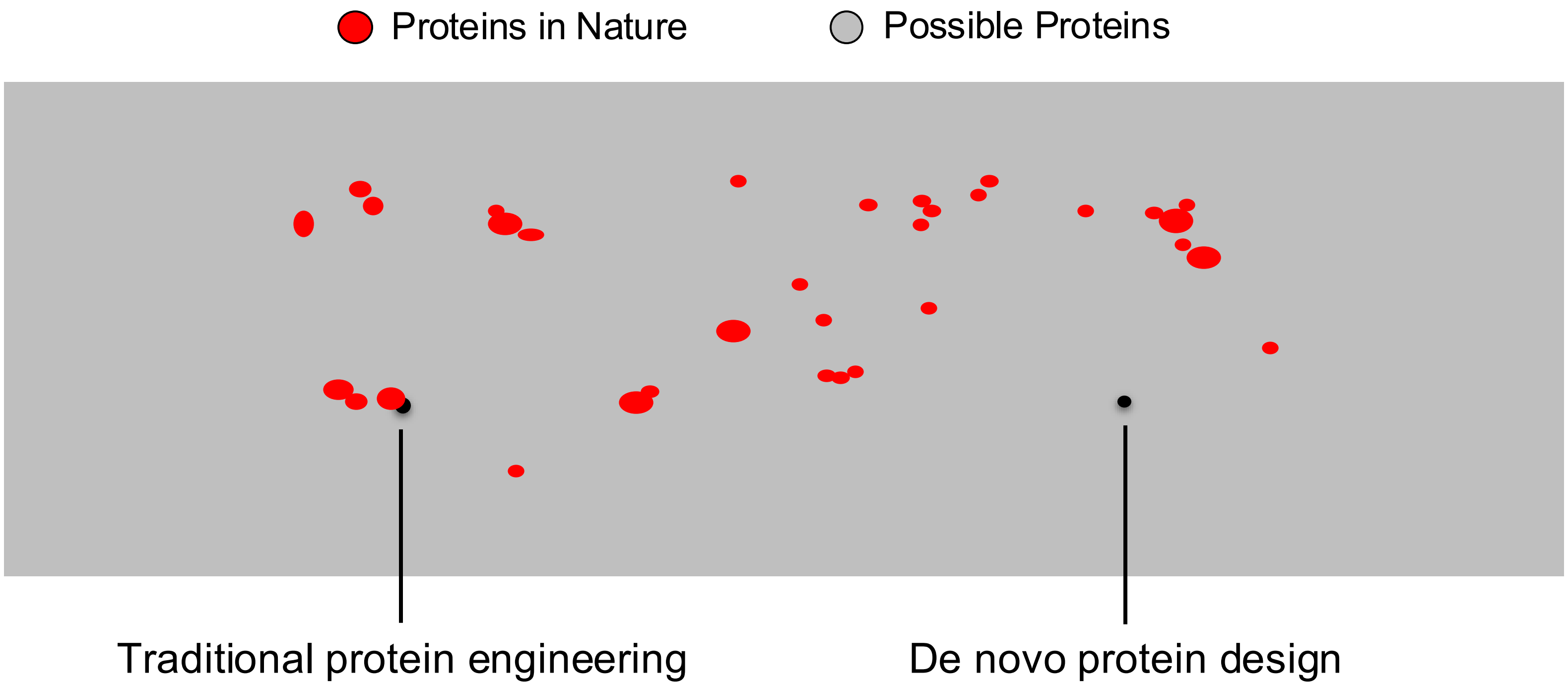
Biology



Design



A vast universe of possible proteins



Number of 100-residue amino acid sequences: 20^{100} = $\mathbf{10^{130}}$
Number of naturally occurring proteins: ~$\mathbf{10^{15}}$

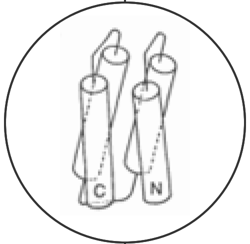
A brief history of protein design

1988 now

A brief history of protein design

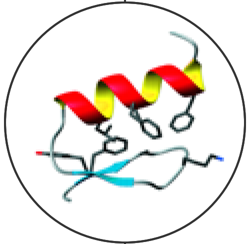
NEW STRUCTURES

1988



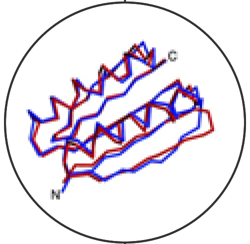
Bill DeGrado
University of California,
San Francisco

1997



Steve Mayo
California Institute
of Technology

2003



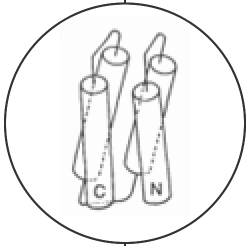
Brian Kuhlman
University of North
Carolina at Chapel Hill

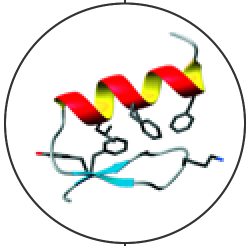
now

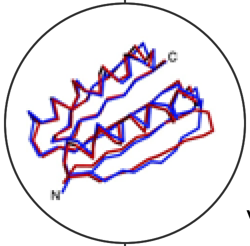
A brief history of protein design

NEW STRUCTURES — NEW FUNCTIONS

1988	1997	2003	2005	2008	now







Rosetta@Home
Volunteer Computing

Foldit
Online Game

1,000s of Projects & Researchers

Bill DeGrado
University of California, San Francisco

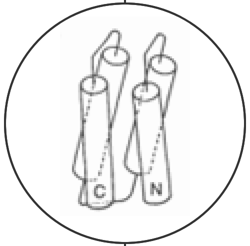
Steve Mayo
California Institute of Technology

Brian Kuhlman
University of North Carolina at Chapel Hill

A brief history of protein design

NEW STRUCTURES | NEW FUNCTIONS | NEW ERA

1988



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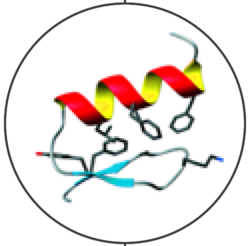

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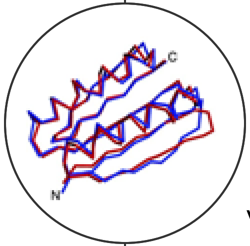


Brian Kuhlman
University of North Carolina at Chapel Hill

2005

Rosetta@Home
Volunteer Computing

2008

Foldit
Online Game

1,000s of Projects & Researchers

2021–now

Designing proteins with RFdiffusion

Inspired by deep-learning methods for generating synthetic images.

e.g. Stable Diffusion, DALL-E

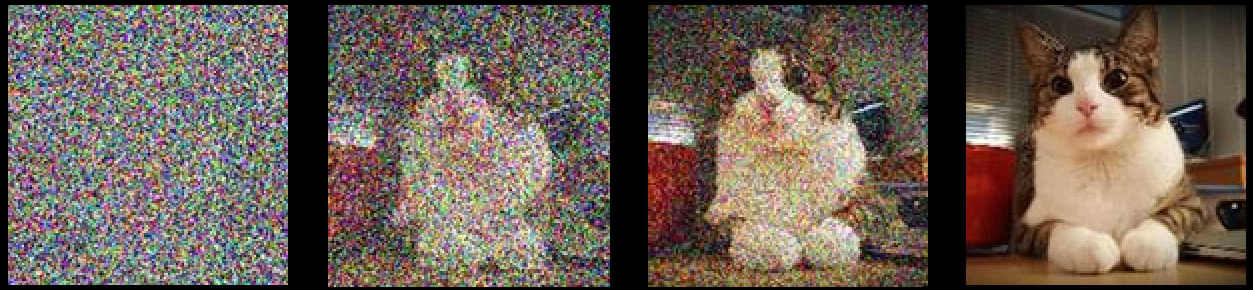
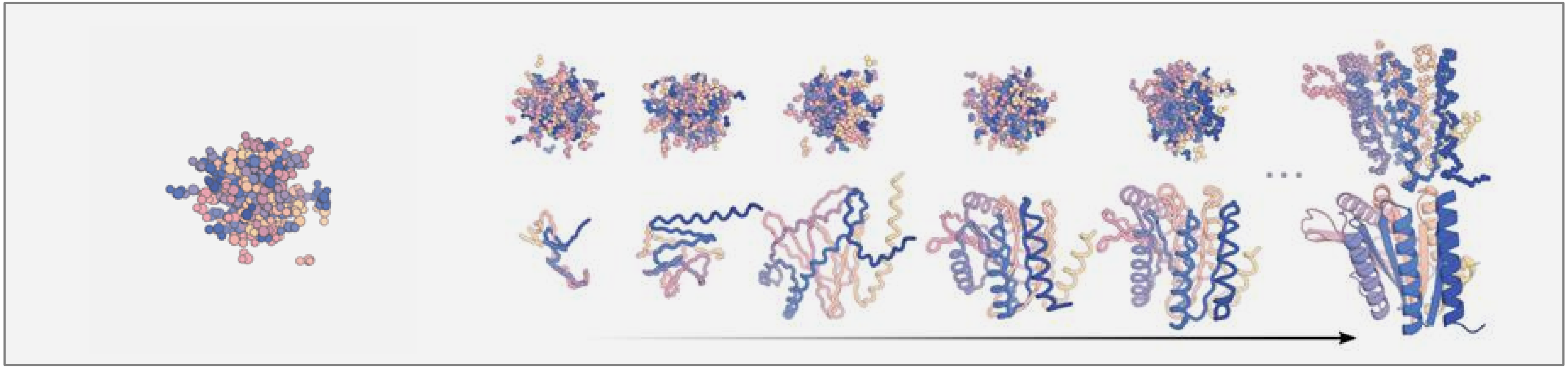
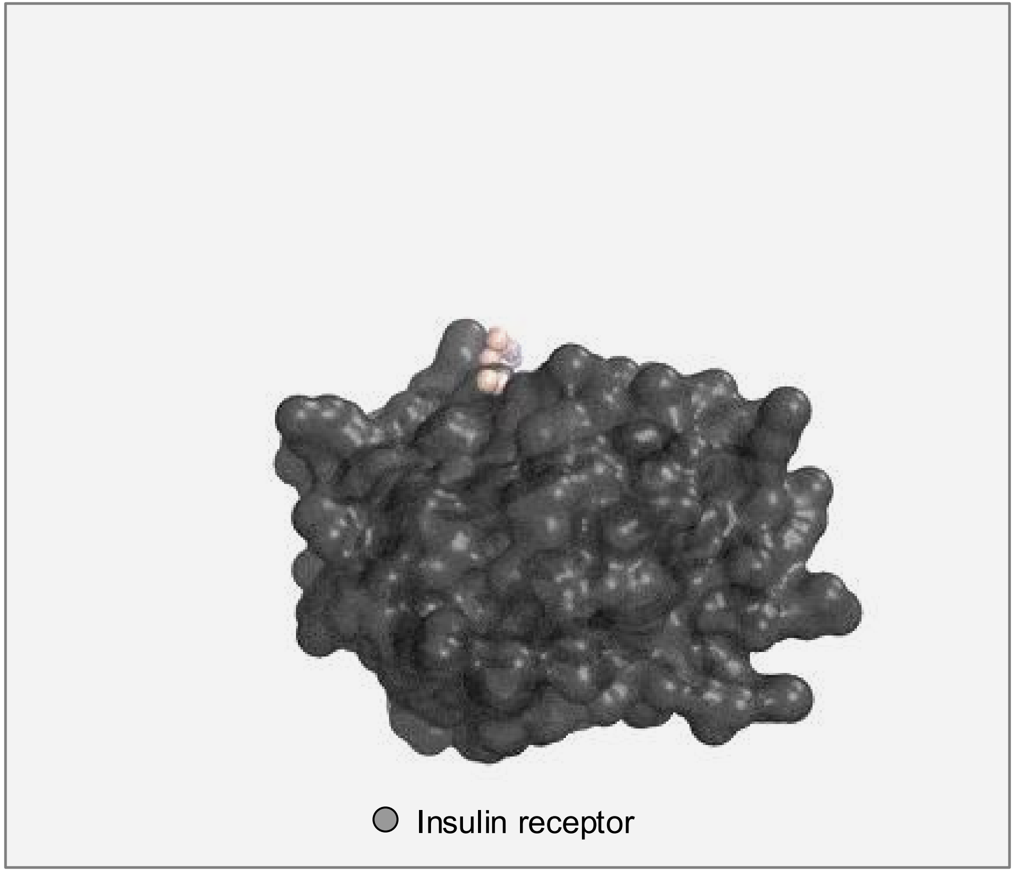


Image: Arash Vahdat and Karsten Kreis (NVIDIA)



Joe Watson, David Juergens, Nathaniel Bennett, Brian Trippe, Jason Yim, Helen Eisenach, Woody Ahern, et al. Nature, 2023

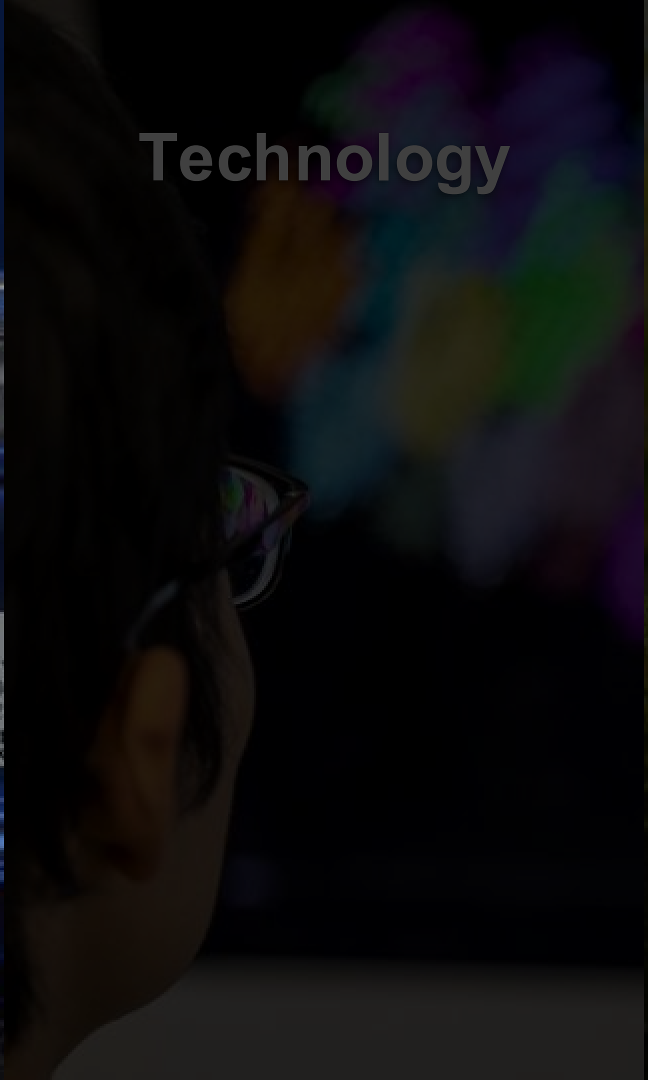
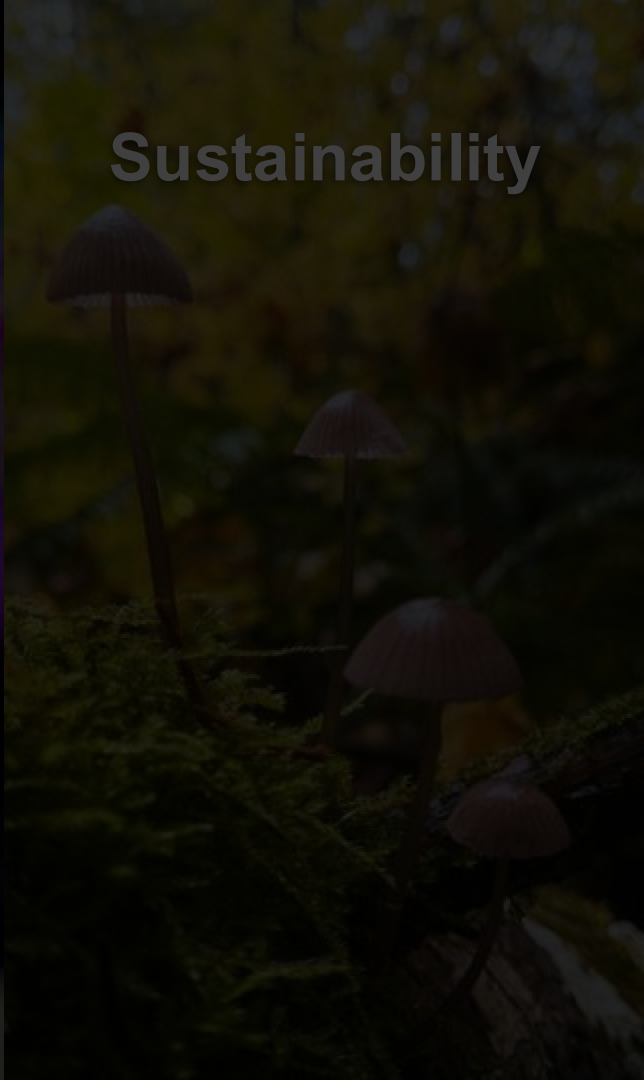
Diffusion of an insulin mimic



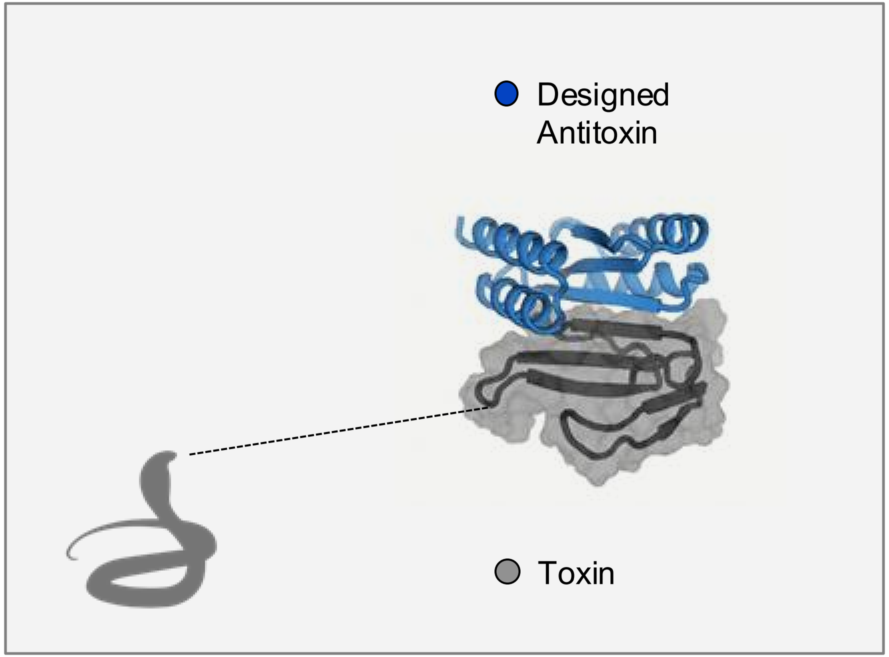
Medicine

Technology

Sustainability


Medicine
SARS-CoV-2 vaccine
Lot Number: U0722001
DOM: 2022.02.08
SK bioscience

Technology

Sustainability

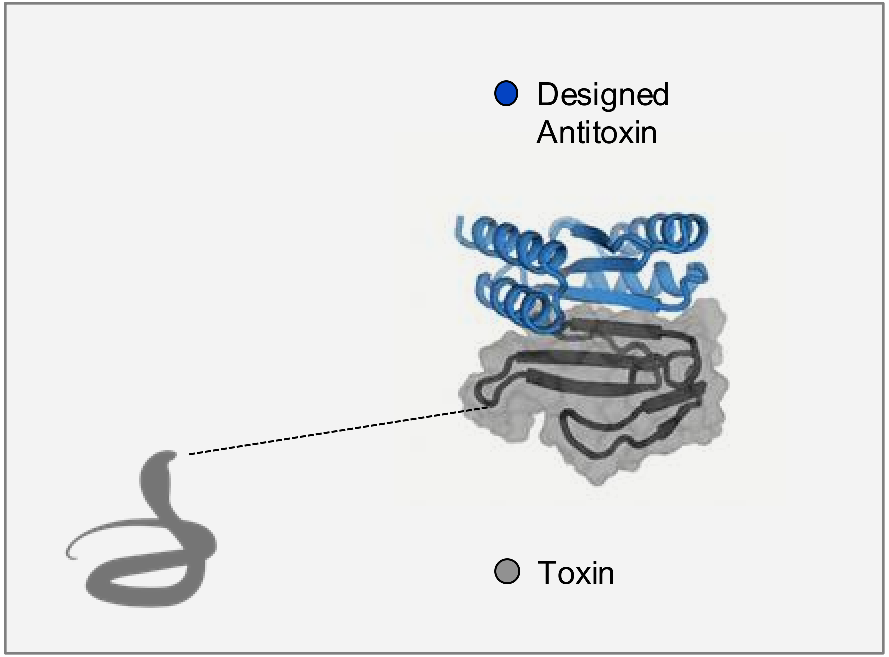
Neutralizing snake toxin



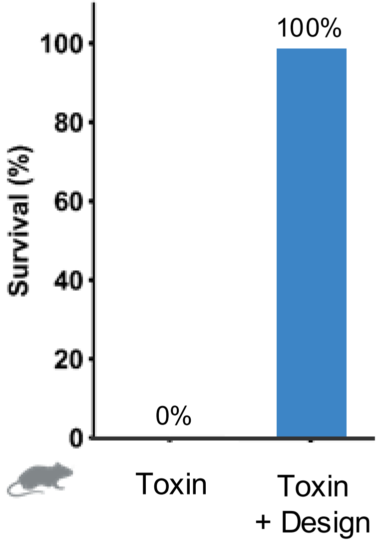
with Jenkins Lab (Technical University of Denmark)

Susana Vázquez Torres et al. Research Square (preprint), 2024

Neutralizing snake toxin



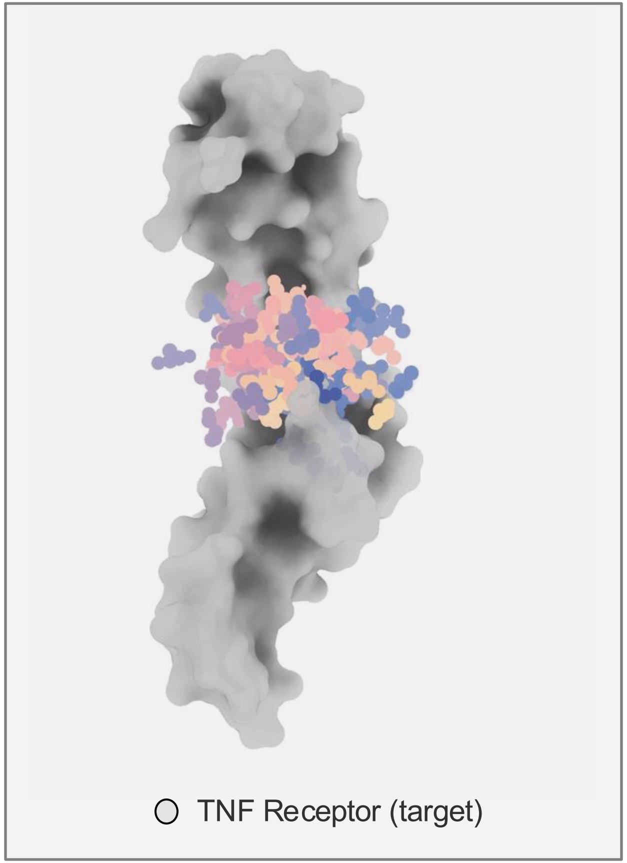
Protects animals from
lethal doses of cobratoxin.



with Jenkins Lab (Technical University of Denmark)

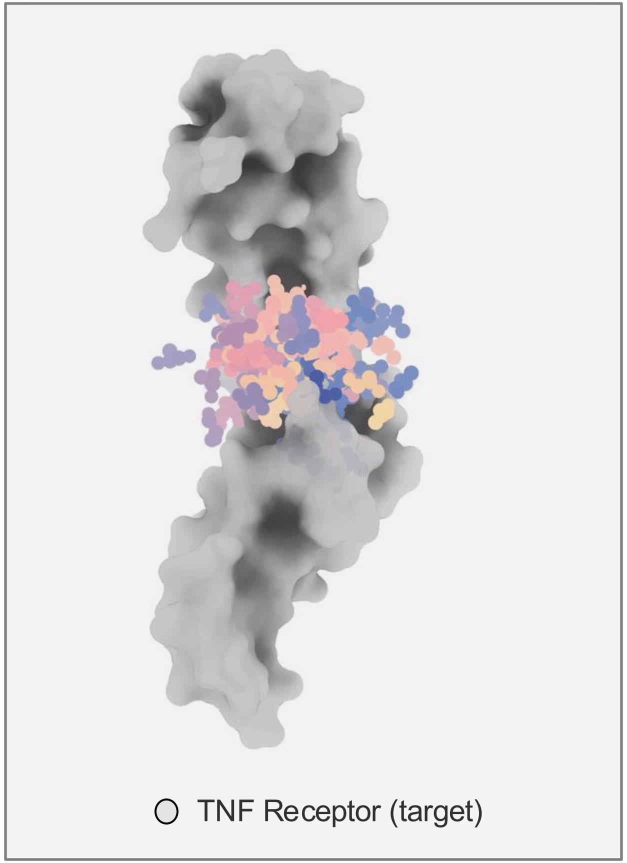
Susana Vázquez Torres et al. Research Square (preprint), 2024

Suppressing inflammation

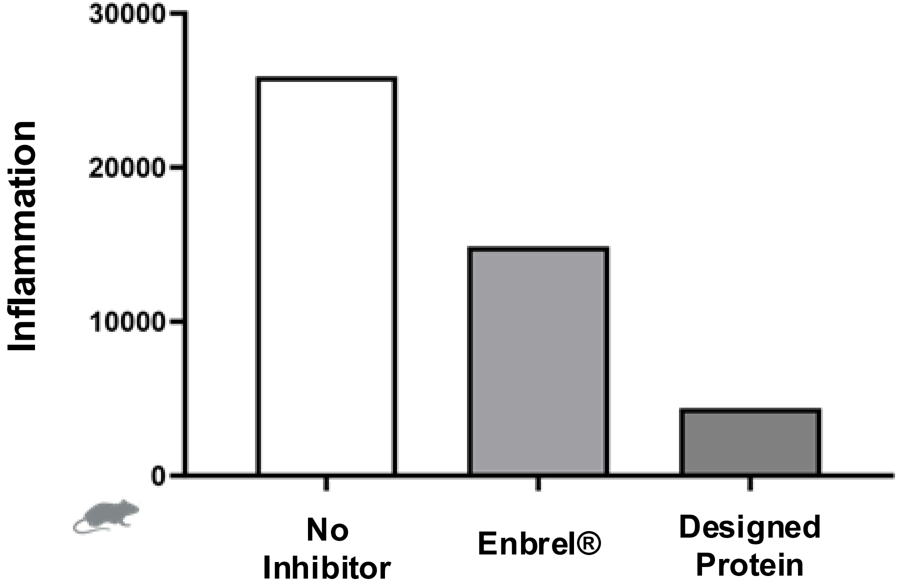


Matthias Glögl et al. Science, 2024

Suppressing inflammation

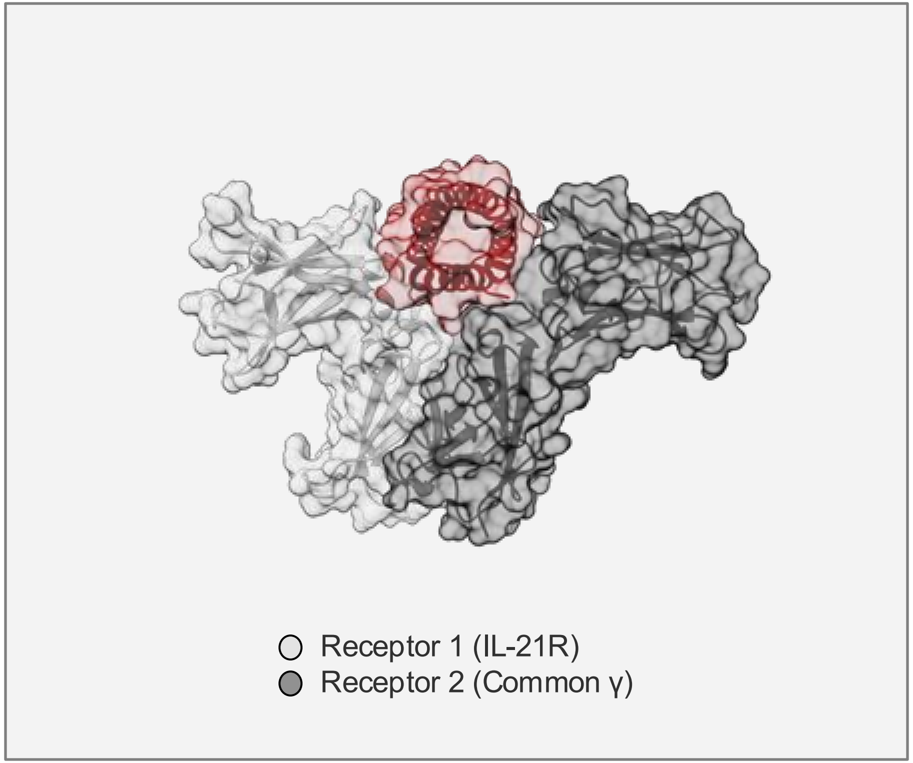


More potent than current medicine (Enbrel®) at inhibiting inflammation.



Matthias Glögl et al. Science, 2024

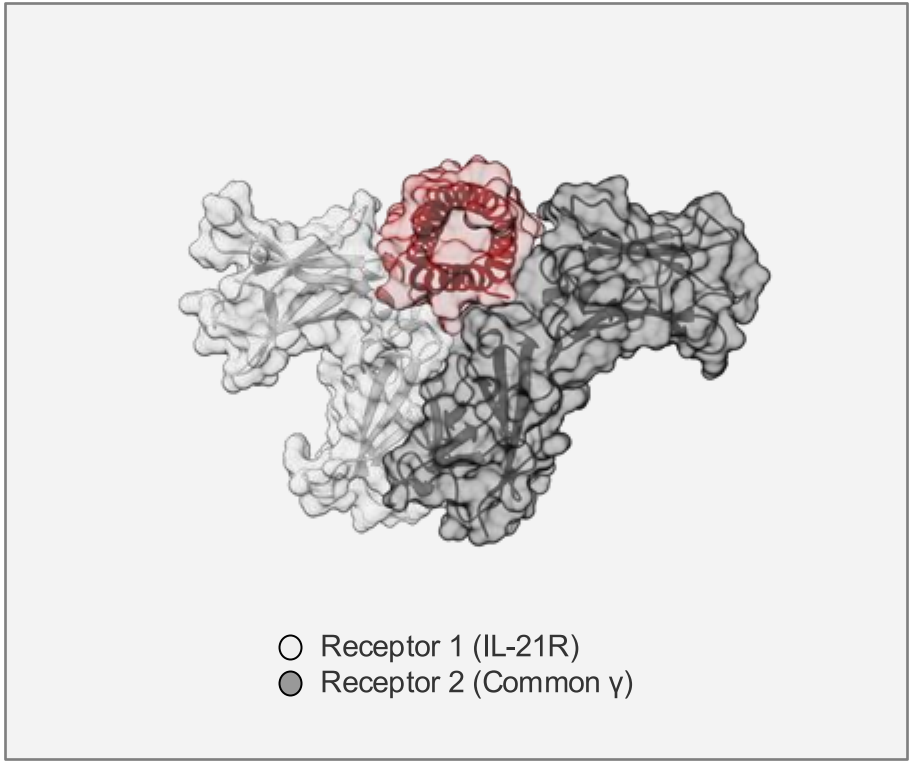
Shrinking tumors

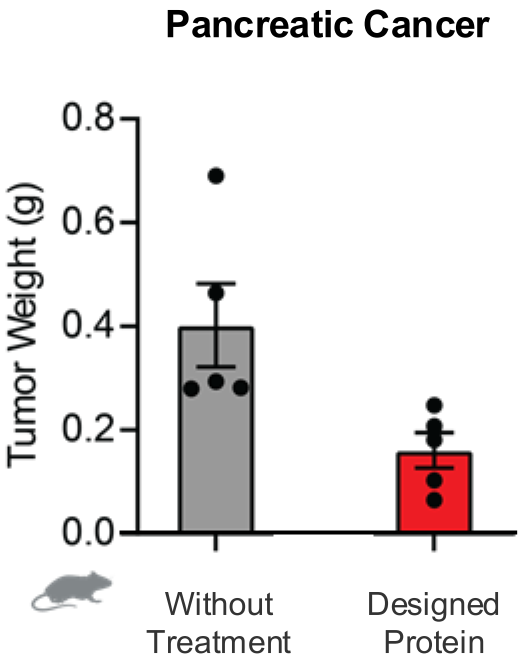


with Dougan Lab (Dana-Farber Cancer Institute)

Jungho Chun, et al. bioRxiv (preprint), 2024

Shrinking tumors

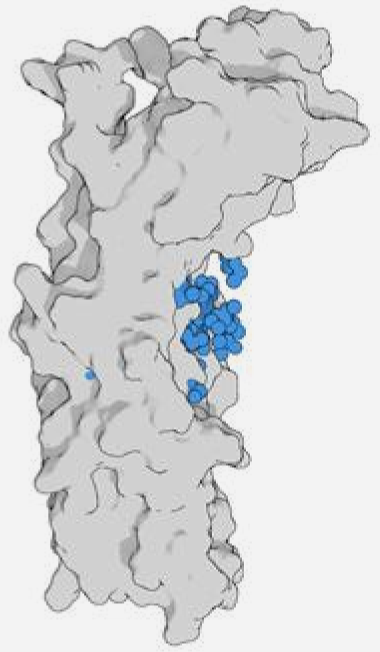




with Dougan Lab (Dana-Farber Cancer Institute)

Jungho Chun, et al. bioRxiv (preprint), 2024

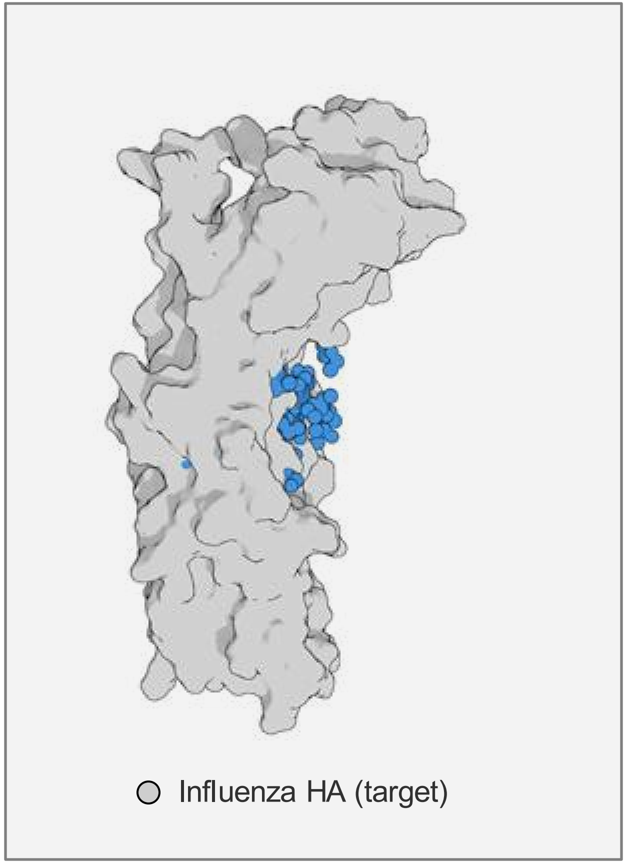
Targeting influenza with de novo antibodies

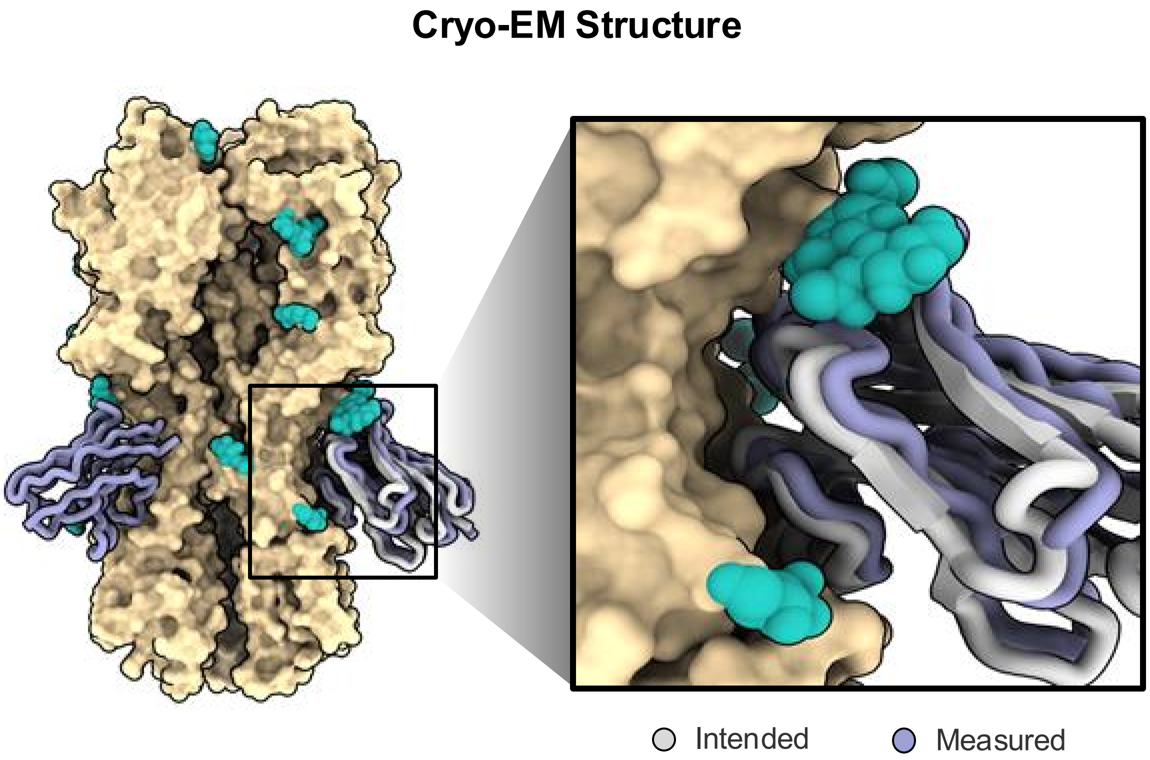


Influenza HA (target)

Nathaniel Bennett, Joseph Watson, Robert Ragotte, Andrew Borst, et al, bioRxiv (preprint), 2024

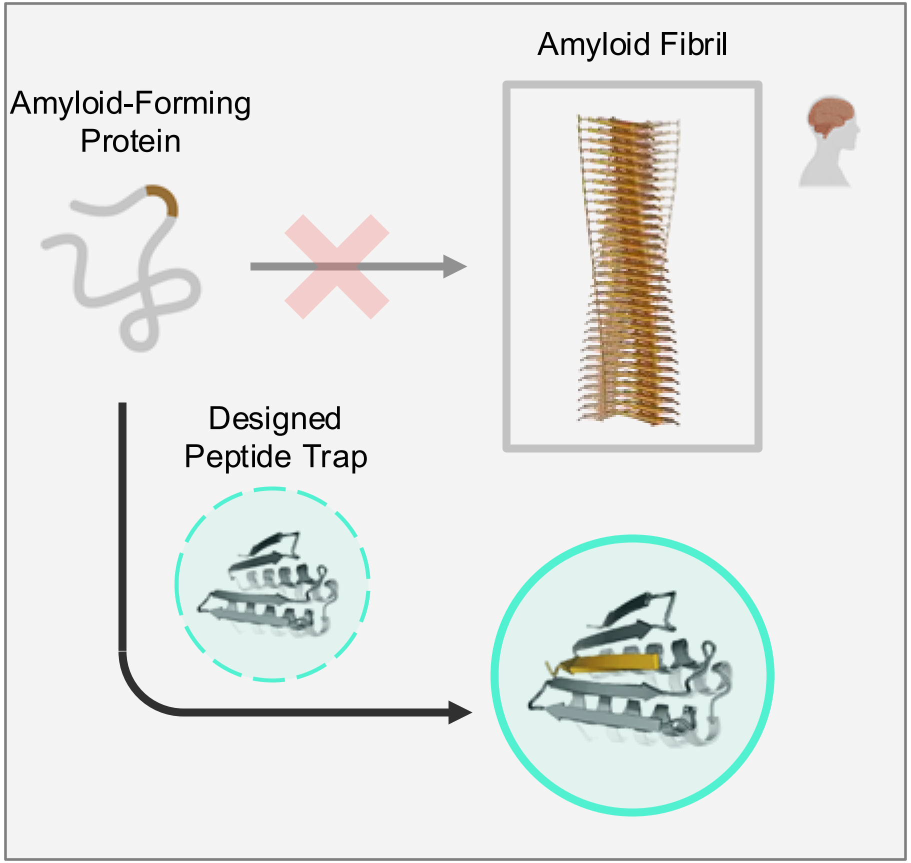
Targeting influenza with de novo antibodies





Nathaniel Bennett, Joseph Watson, Robert Ragotte, Andrew Borst, et al, bioRxiv (preprint), 2024

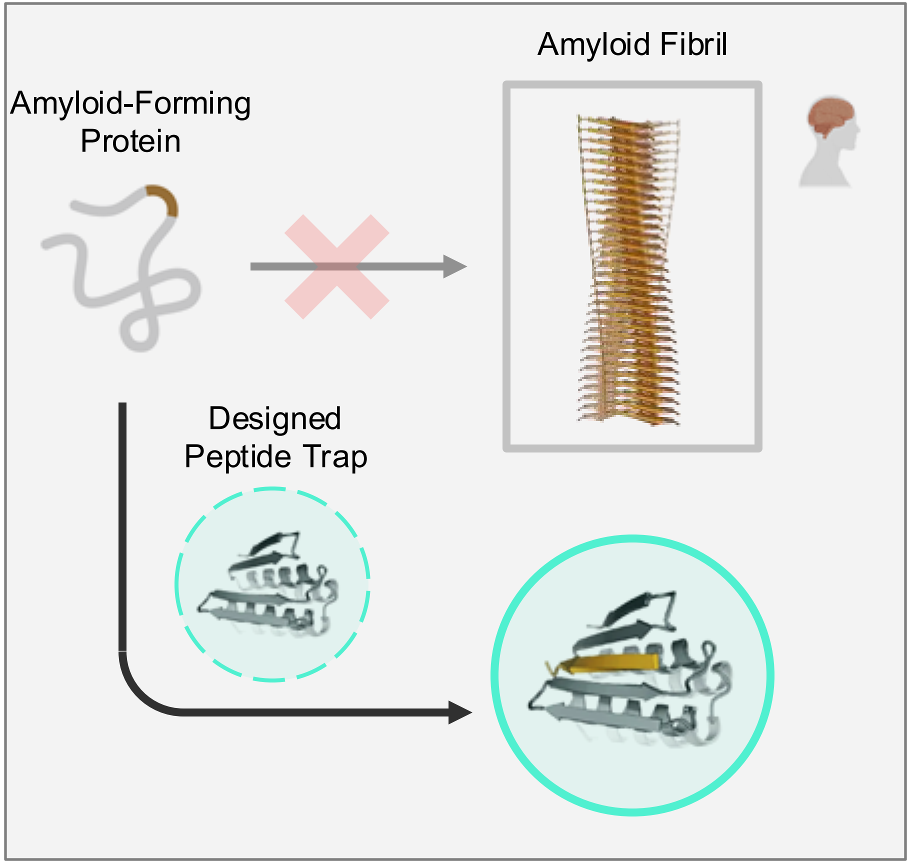
Blocking Alzheimer's-associated amyloid fibrils



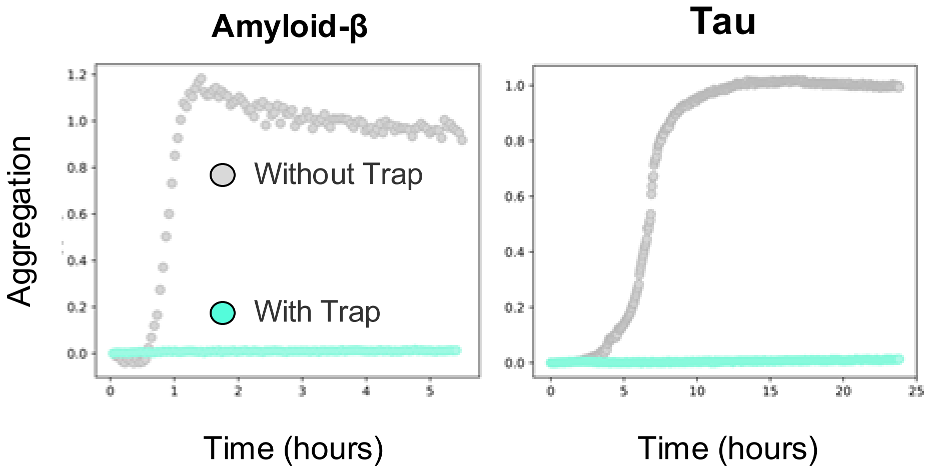
with Knowles Lab (University of Cambridge)

Danny Sahtoe, Hannah Han et al. Nature Chemical Biology, 2024

Blocking Alzheimer's-associated amyloid fibrils



Prevents fibril formation in the lab.

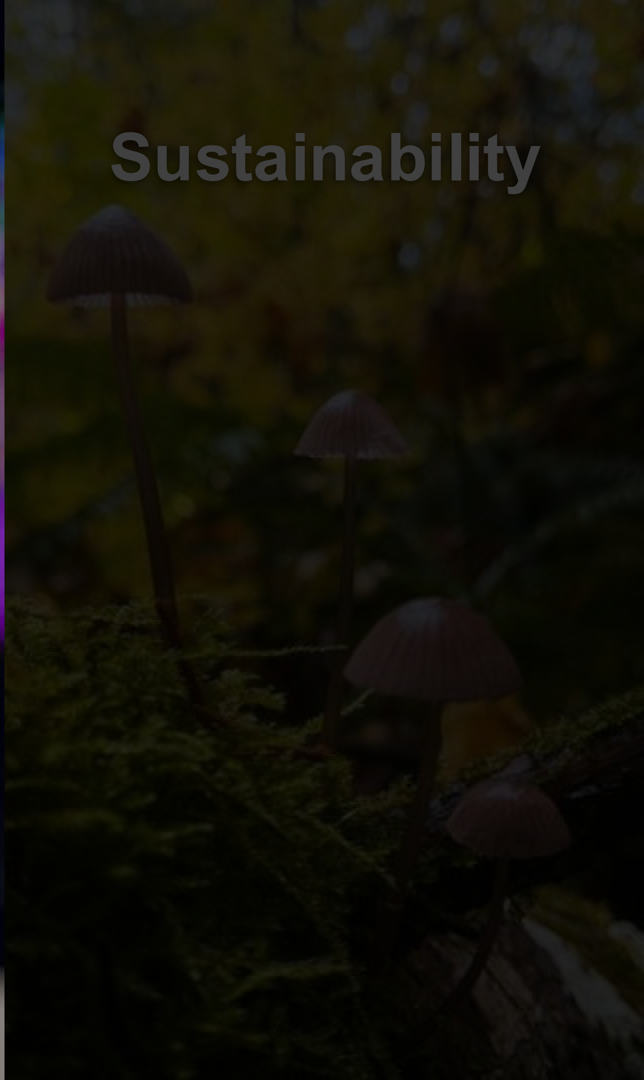


with Knowles Lab (University of Cambridge)

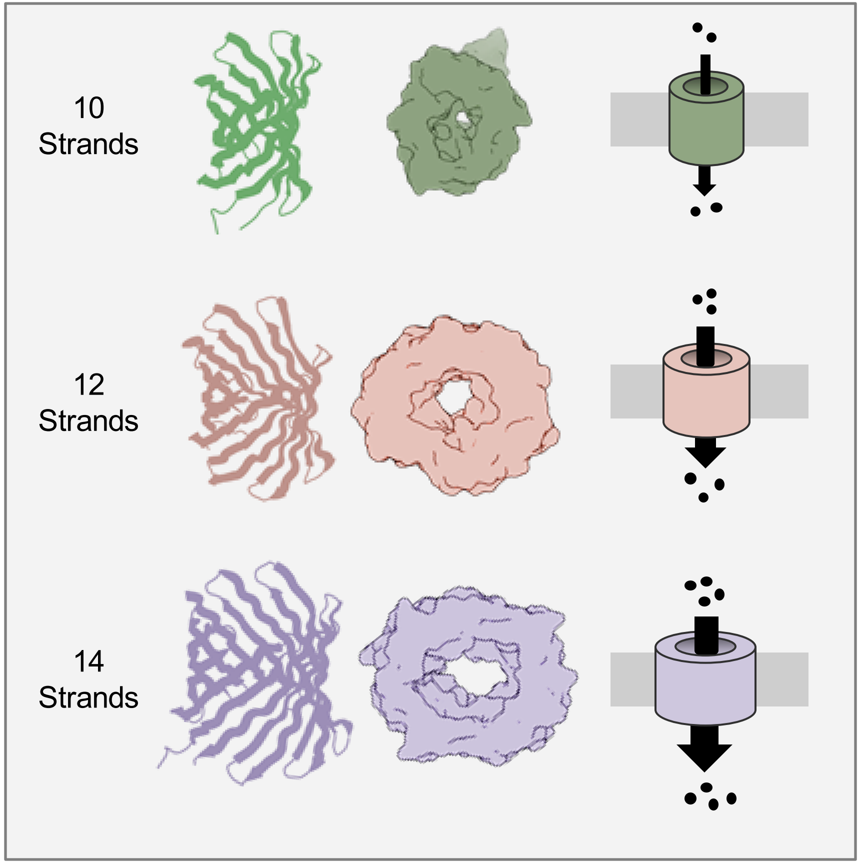
Danny Sahtoe, Hannah Han et al. Nature Chemical Biology, 2024


Medicine
SARS-CoV-2 vaccine
Lot Number: U0722001
DOM: 2022.02.06


Technology


Sustainability

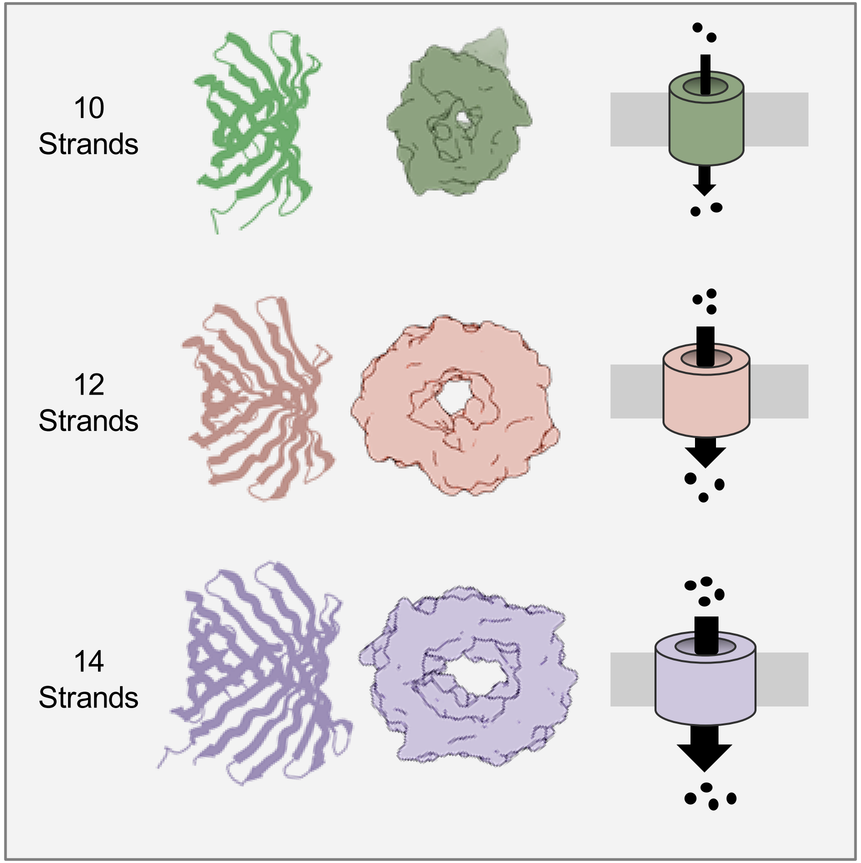
Conductive nanopores

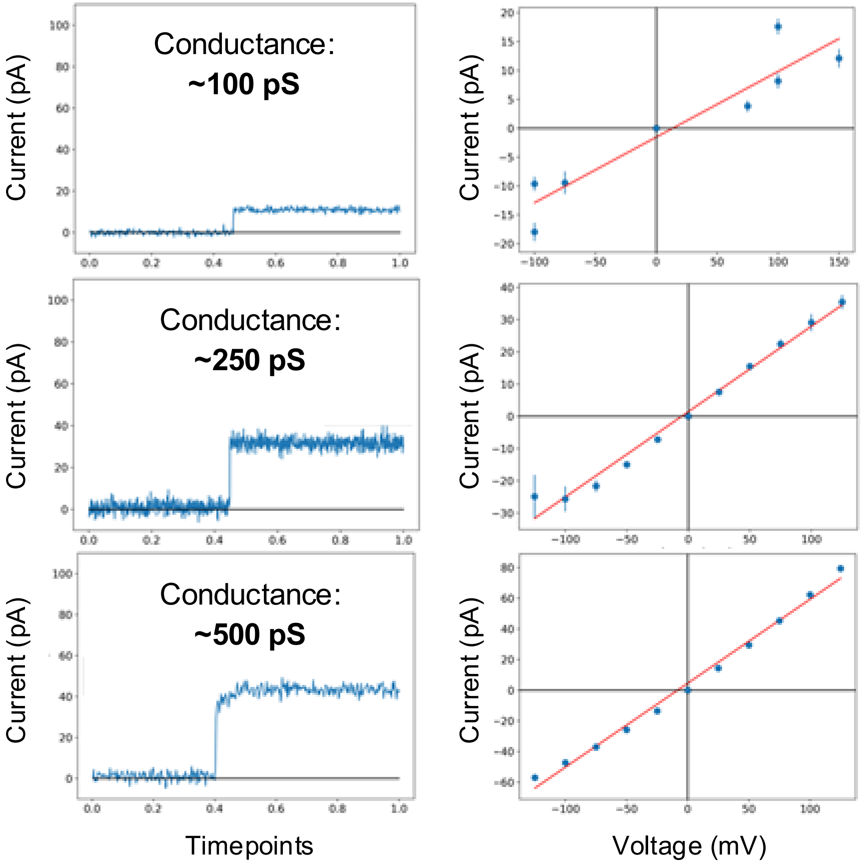


with Vorobieva Lab (VIB-VUB)

Samuel Lemma, Sagardip Majumder, et al. Science, 2024

Conductive nanopores

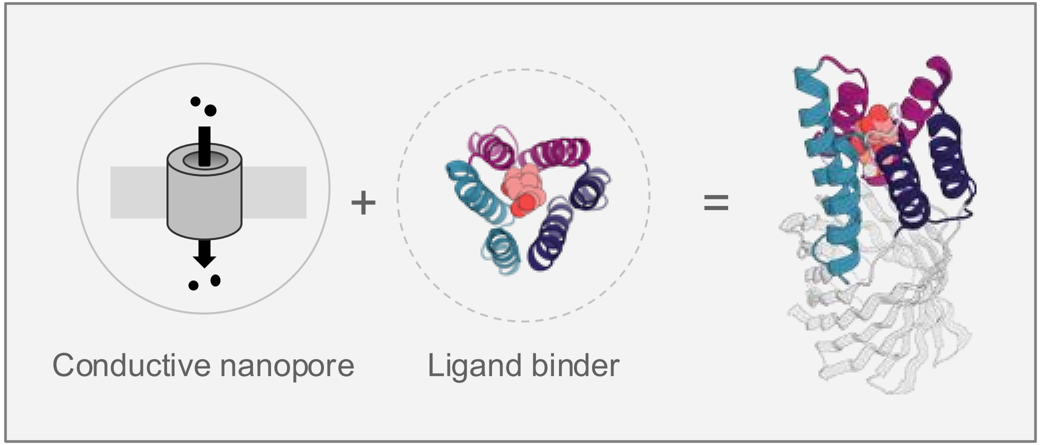




with Vorobieva Lab (VIB-VUB)

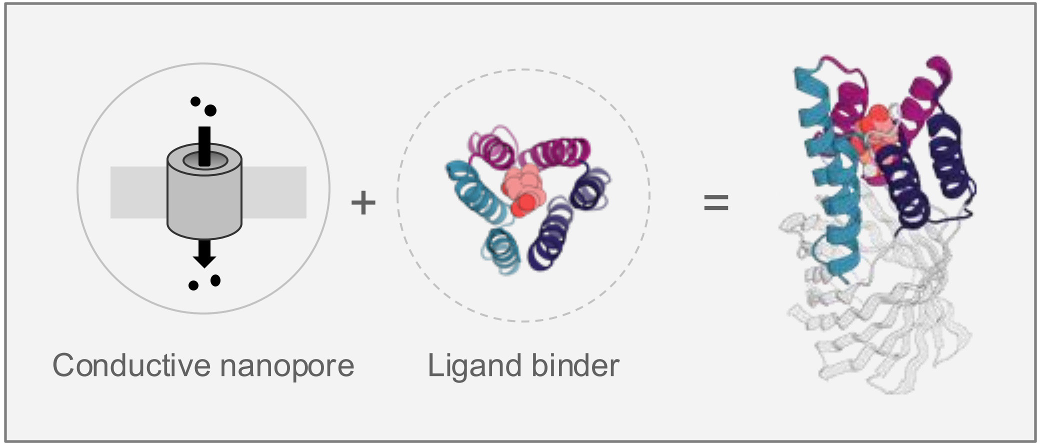
Samuel Lemma, Sagardip Majumder, et al. Science, 2024

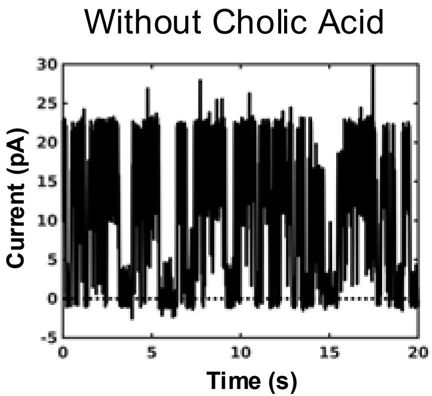
Sensing chemicals

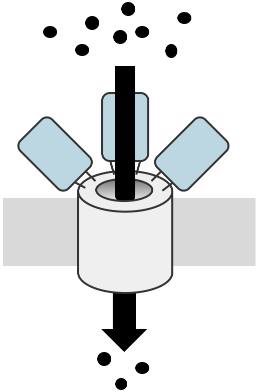


Linna An, et al. Science, 2024

Sensing chemicals







Linna An, et al. Science, 2024

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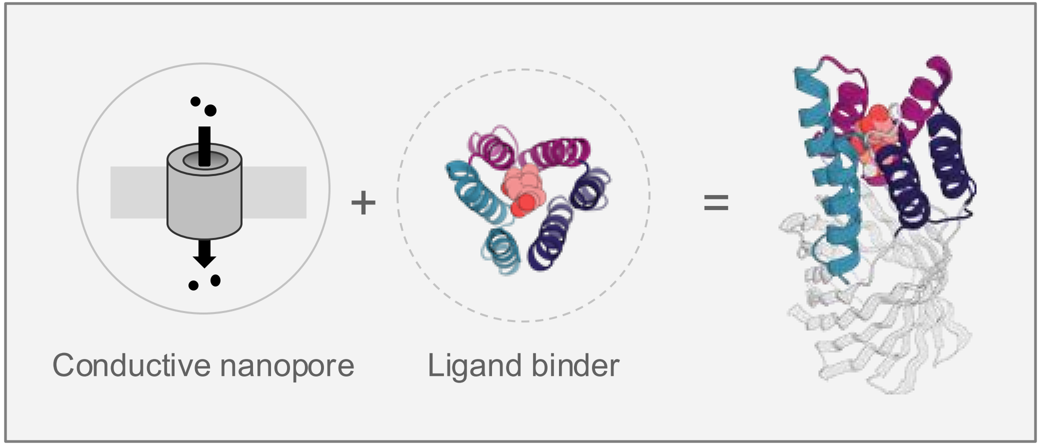
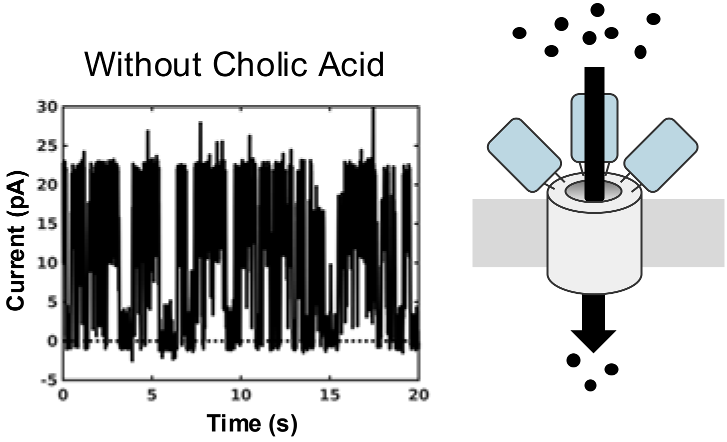
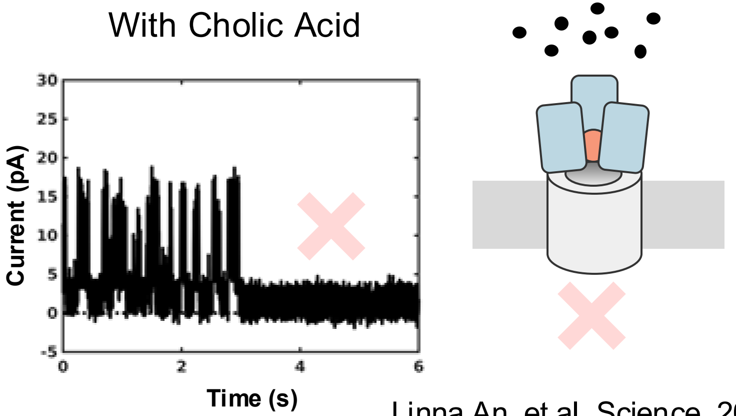


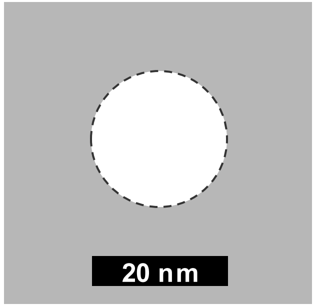


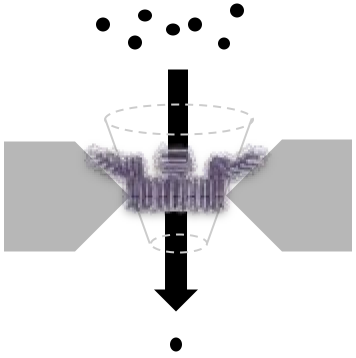


Linna An, et al. Science, 2024

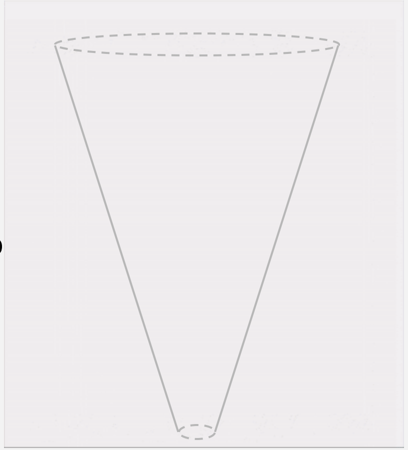
Combining proteins and digital technology

Silicon Nitride Chip





Diffusing pores to insert into silicon



with Gundlach Lab (UW)

Alexis Courbet, Jinwei Xu, Akira Pfeffer, David Bergsman, Jay Werner

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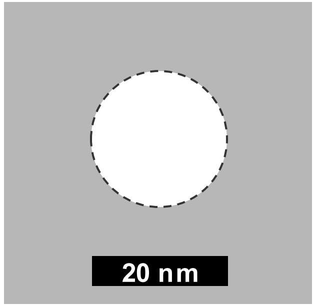
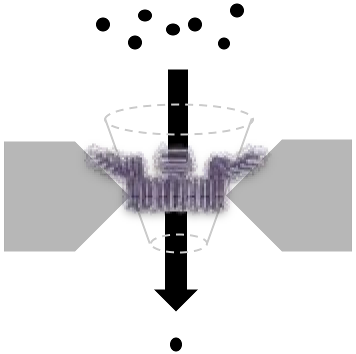
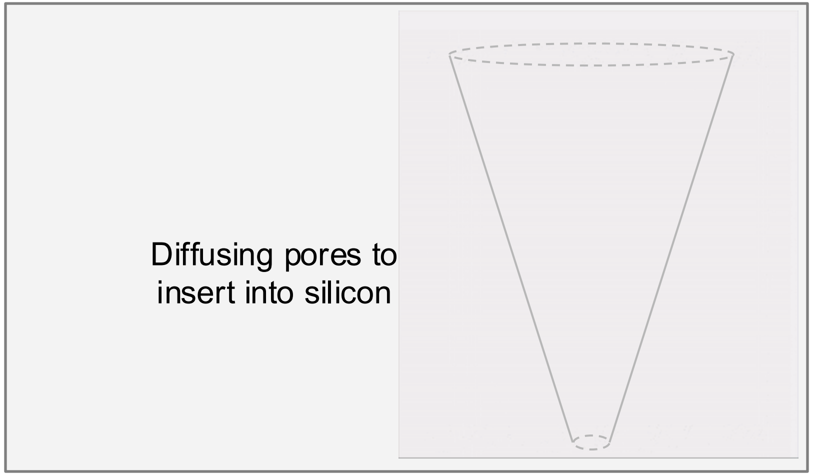
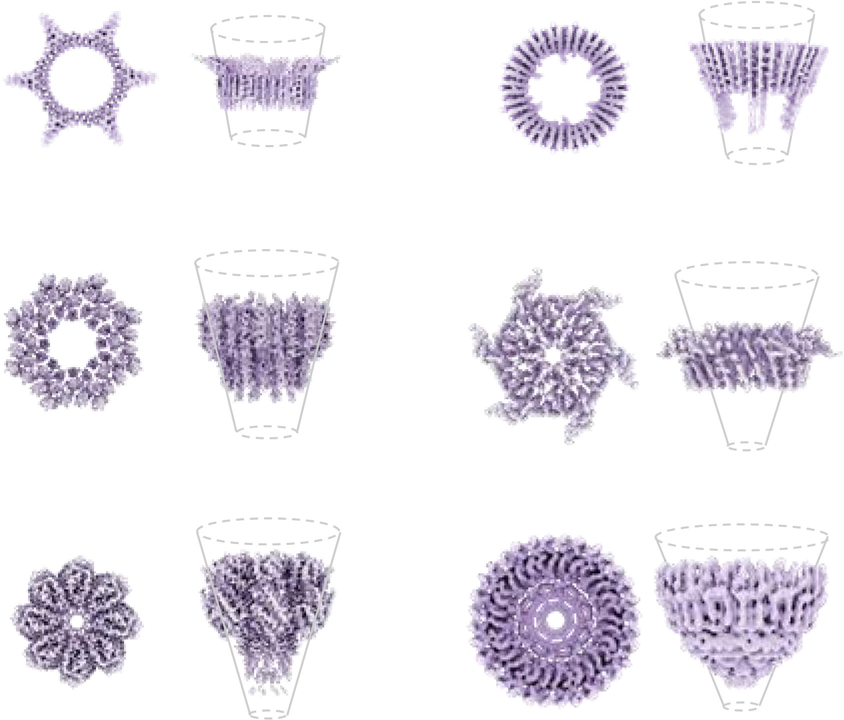






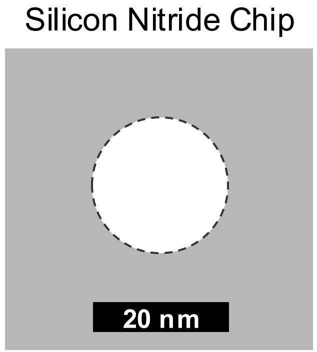
with Gundlach Lab (UW)

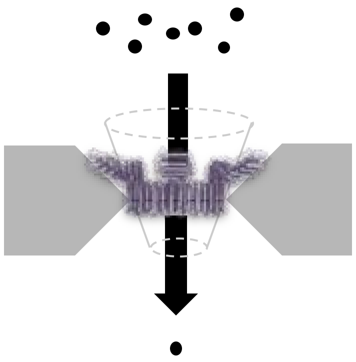
Cryo-EM Structures

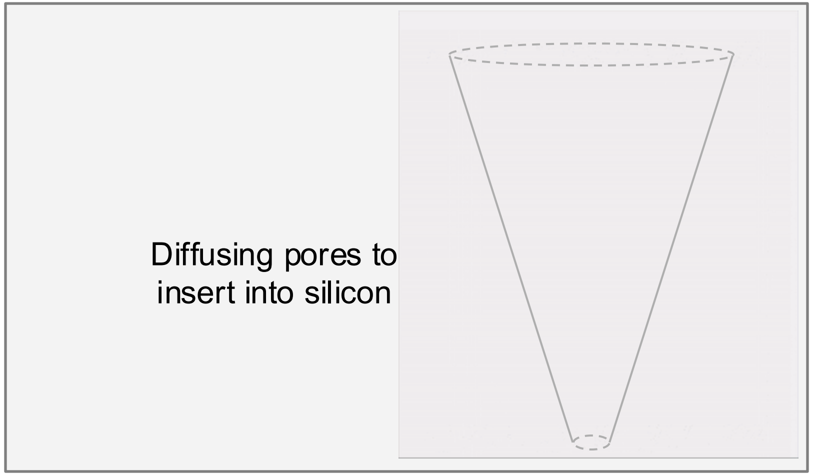


Alexis Courbet, Jinwei Xu, Akira Pfeffer, David Bergsman, Jay Werner

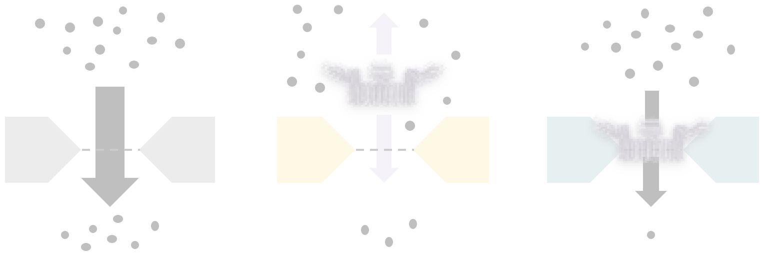
Combining proteins and digital technology

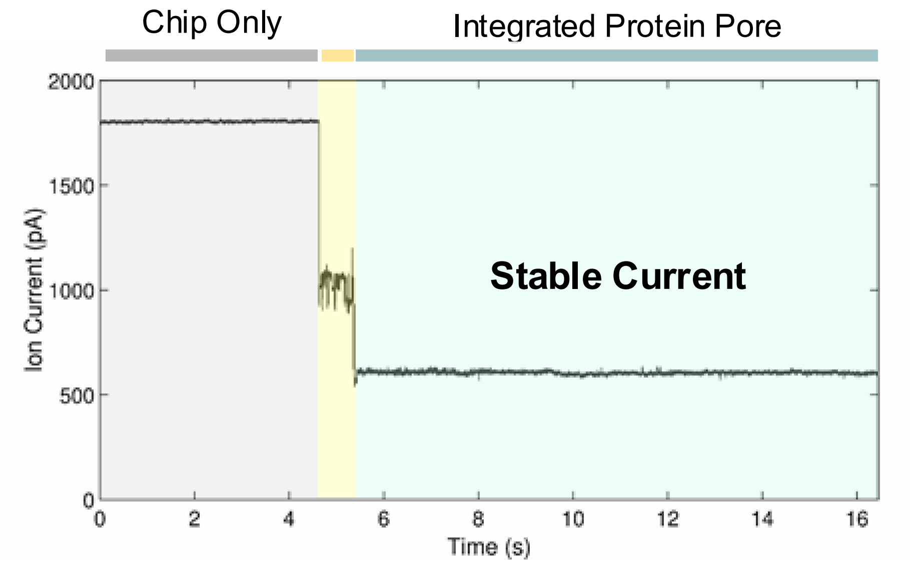






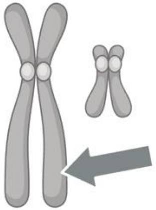
with Gundlach Lab (UW)

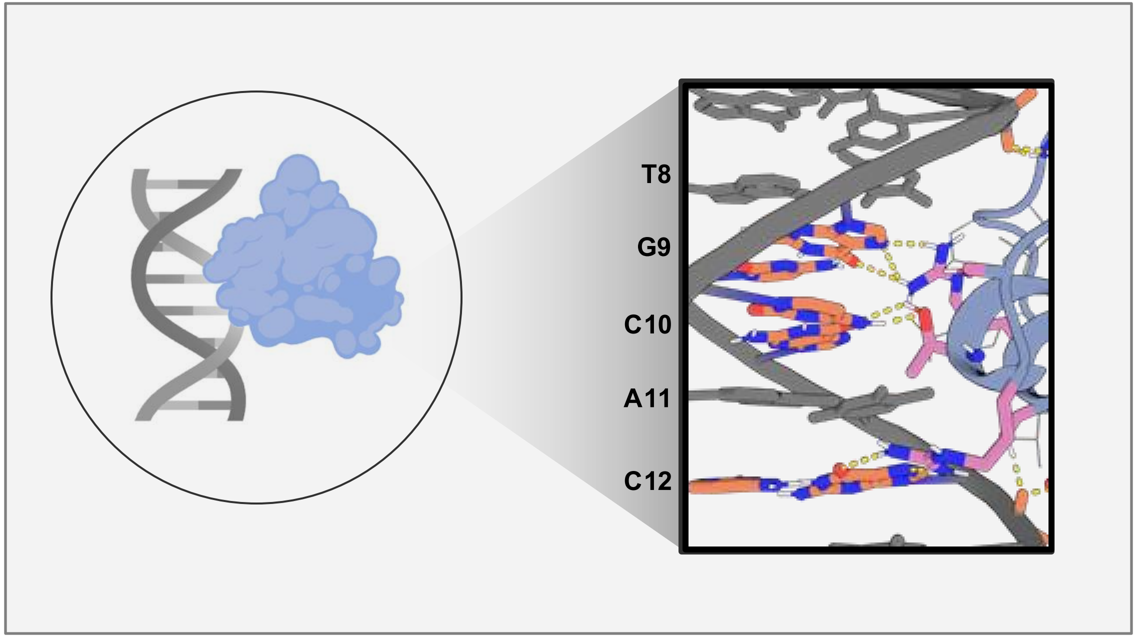




Alexis Courbet, Jinwei Xu, Akira Pfeffer, David Bergsman, Jay Werner

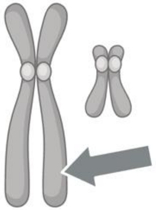
Targeting DNA

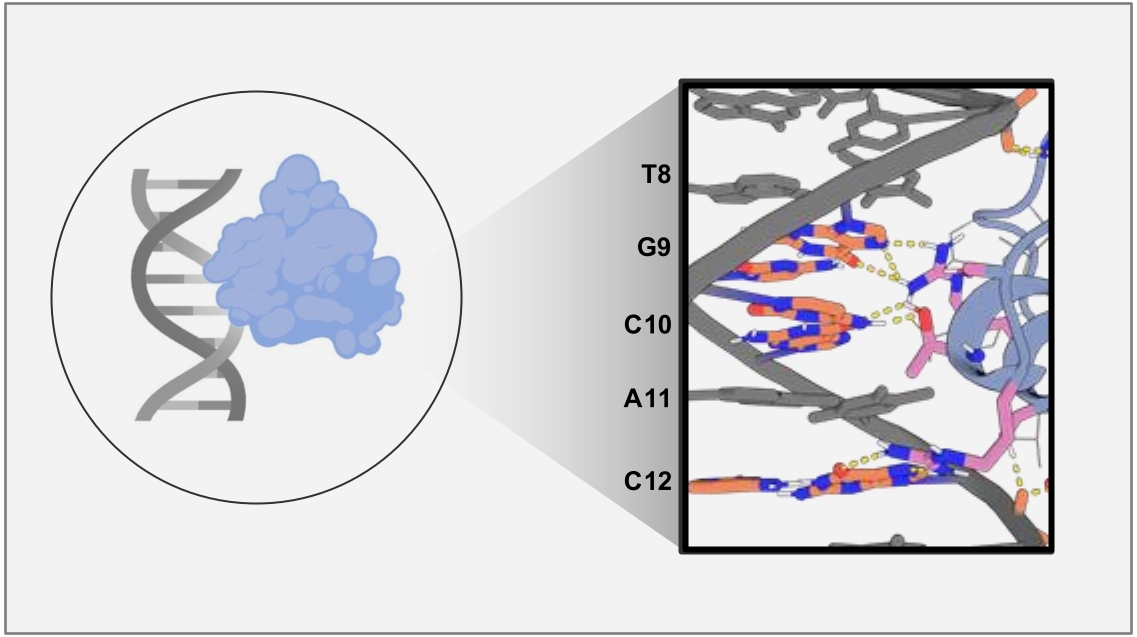




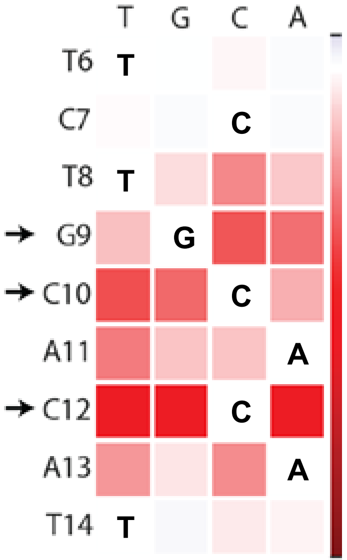
Cameron Glasscock, Robert Pecoraro, Ryan McHugh, et al. bioRvix (preprint), 2023

Targeting DNA





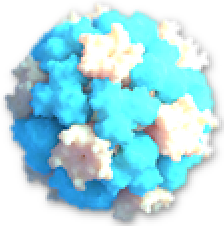
Binding Specificity



Cameron Glasscock, Robert Pecoraro, Ryan McHugh, et al. bioRvix (preprint), 2023

First computationally designed protein medicine

2016



Neil King
UW Medicine

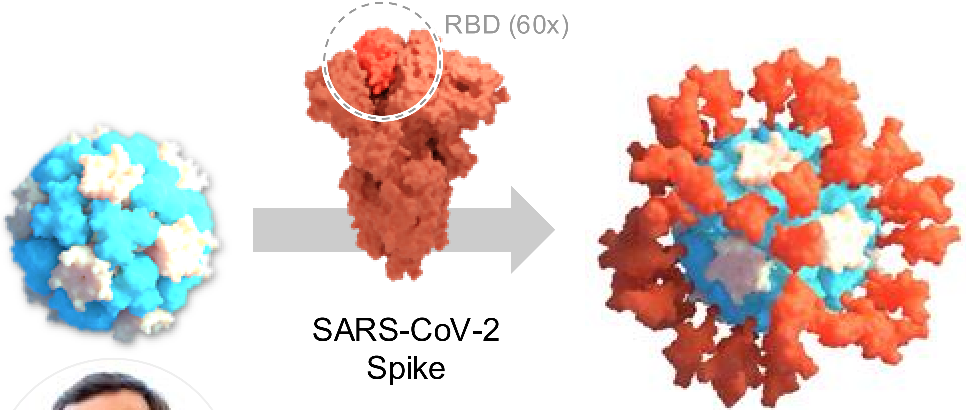
Alexandra Walls, Brooke Fiala, et al. Cell, 2020
Alexandra Walls, et al. Cell, 2021

designed by King and Veesler Labs (UW Medicine)

First computationally designed protein medicine

2016

2020



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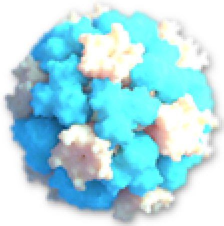
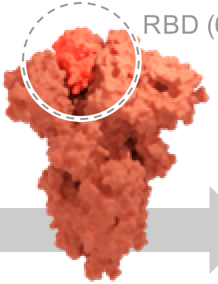
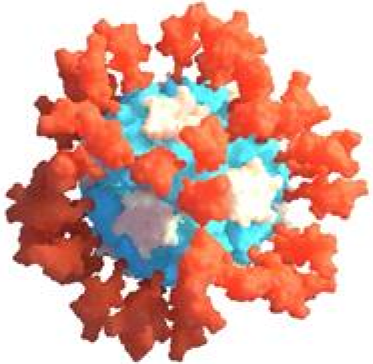


Neil King
UW Medicine



SARS-CoV-2
Spike

2020



2022

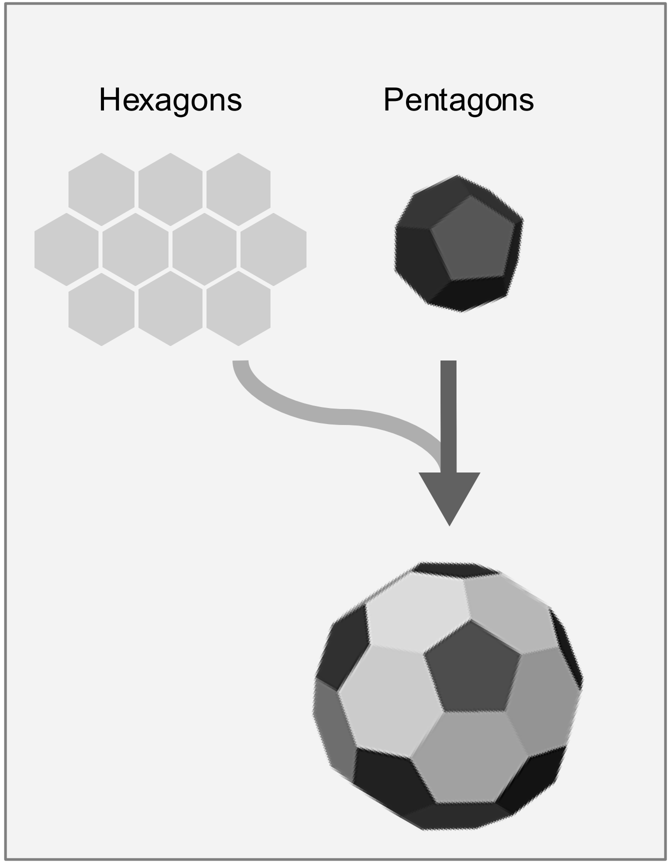
SKYCovione™ COVID-19 vaccine
approved in U.K. & South Korea

image: SK Bioscience

designed by King and Veesler Labs (UW Medicine)

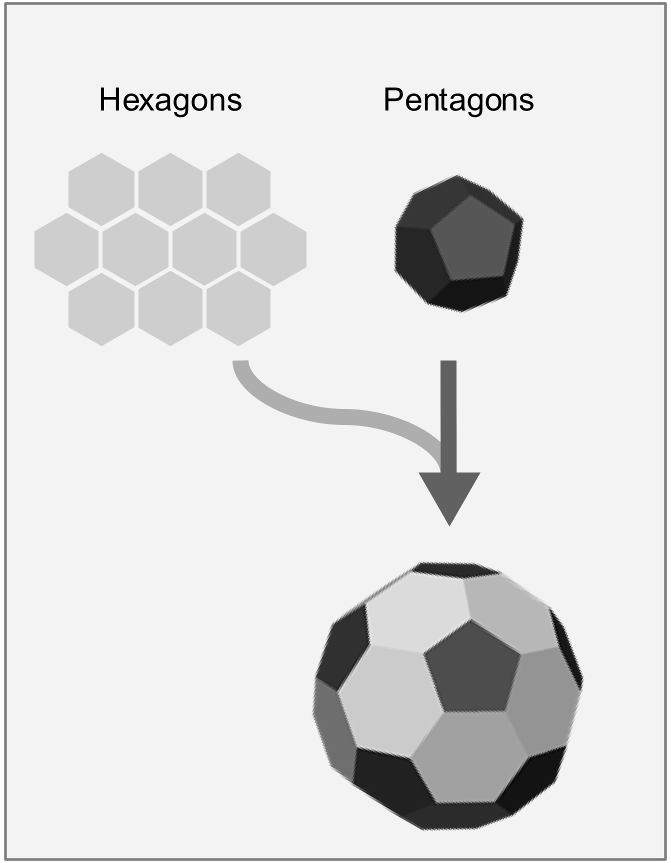
Alexandra Walls, Brooke Fiala, et al. Cell, 2020
Alexandra Walls, et al. Cell, 2021

Larger containers through symmetry breaking



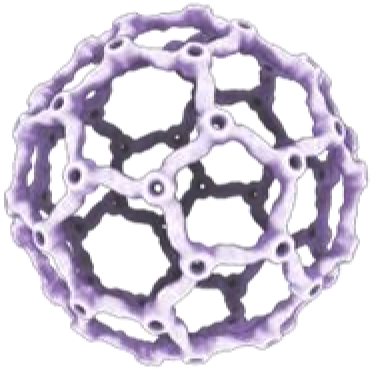
Sangmin Lee, Ryan Kibler, et al. bioRvix (preprint), 2023

Larger containers through symmetry breaking



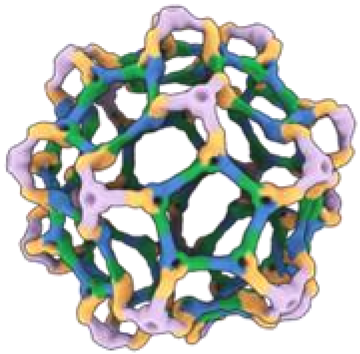
Cryo-EM Structures

Quasisymmetry



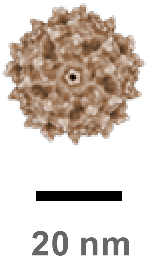
1 unique protein,
180 chains

Pseudosymmetry



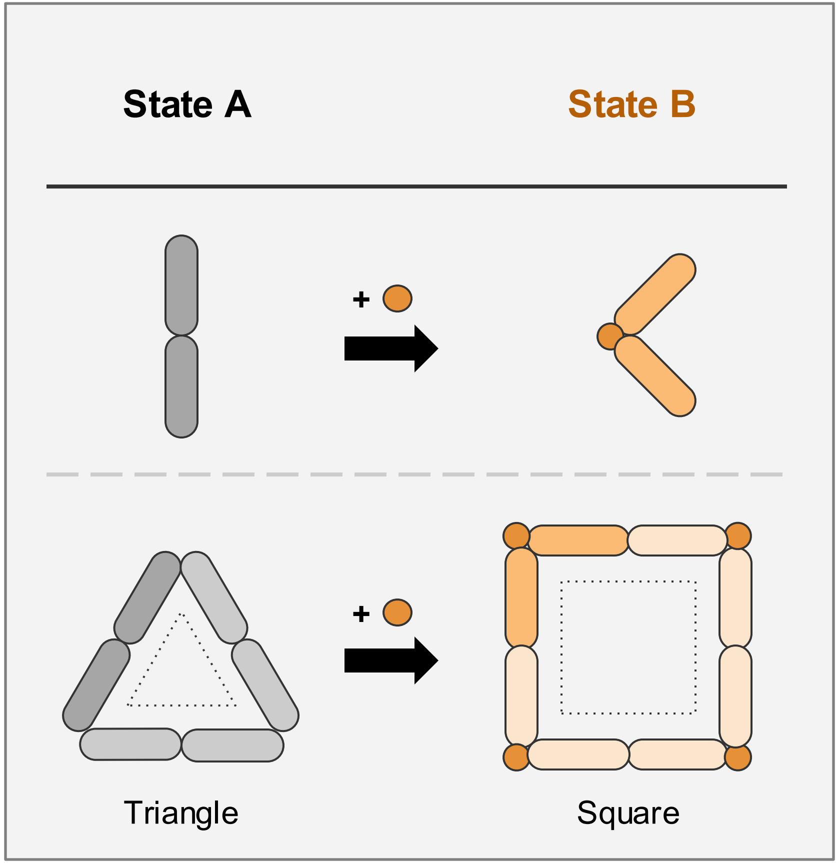
4 unique proteins,
240 chains

AAV
For Scale



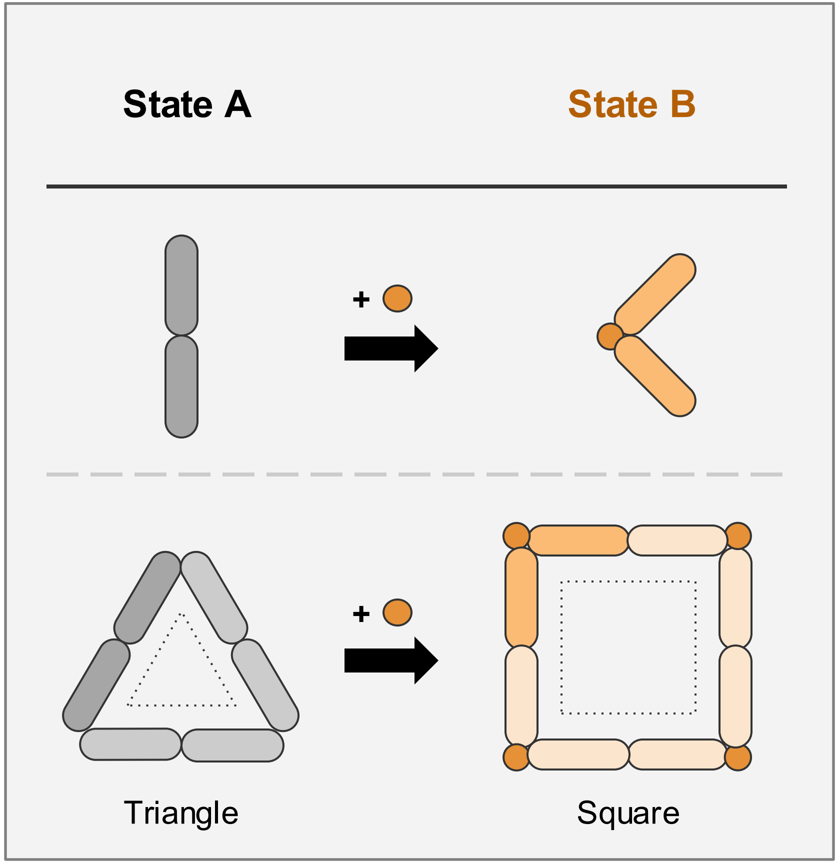
Sangmin Lee, Ryan Kibler, et al. bioRvix (preprint), 2023

Molecular switches

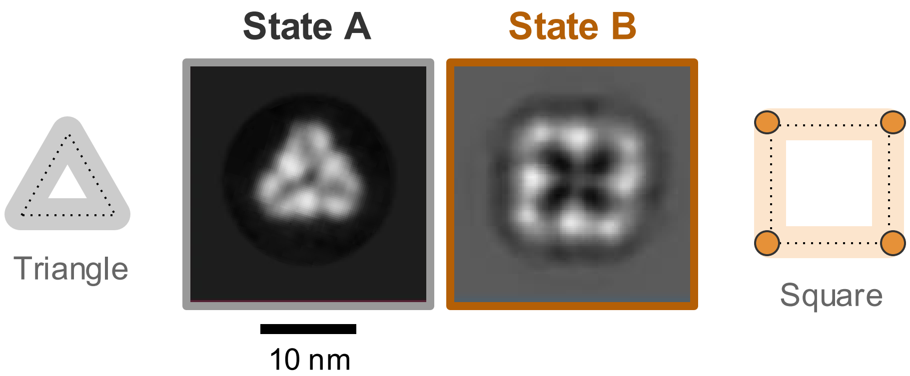


Arvind Pillai, Abbas Idris, et al. Nature, 2024

Molecular switches

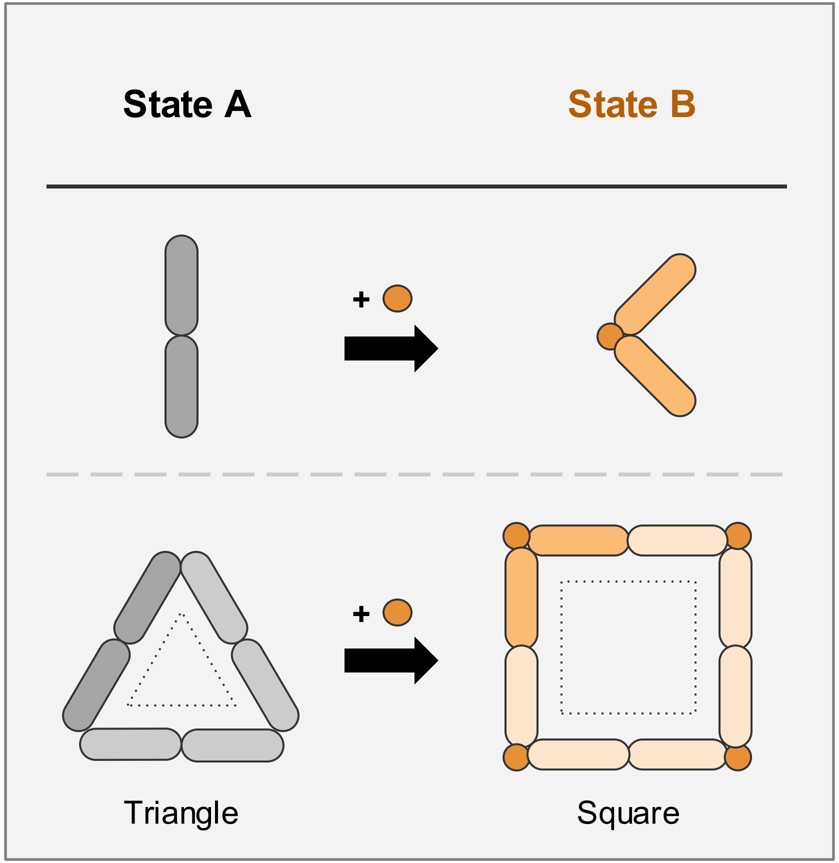


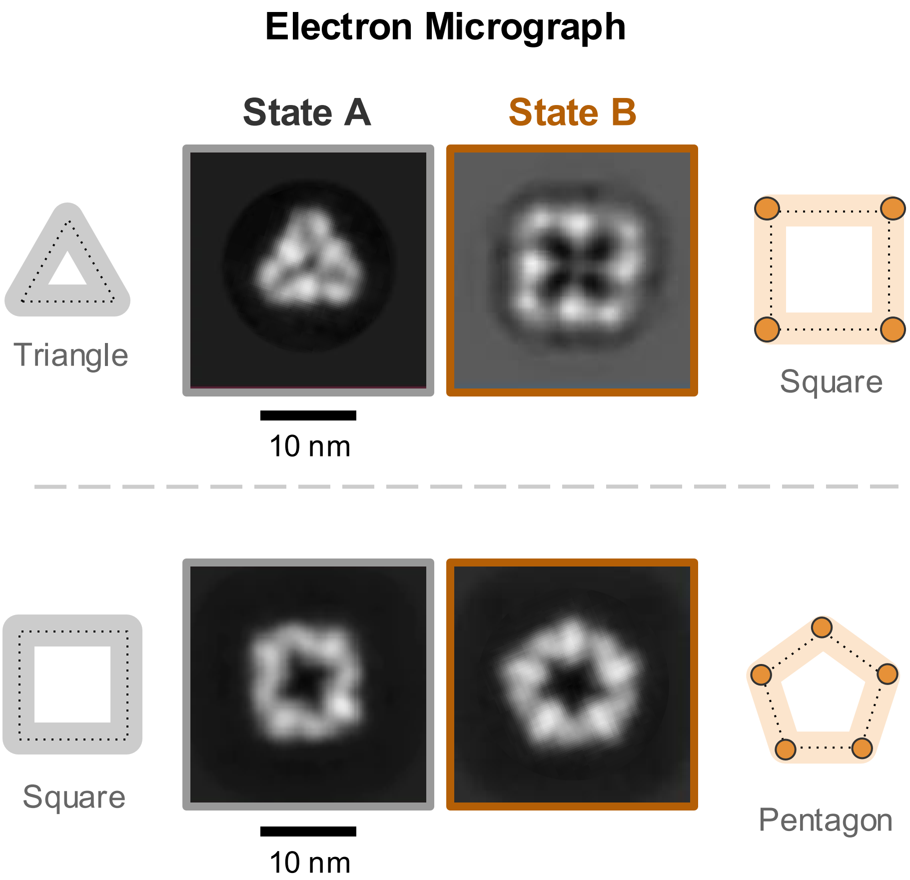
Electron Micrograph



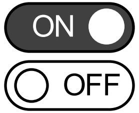
Arvind Pillai, Abbas Idris, et al. Nature, 2024

Molecular switches

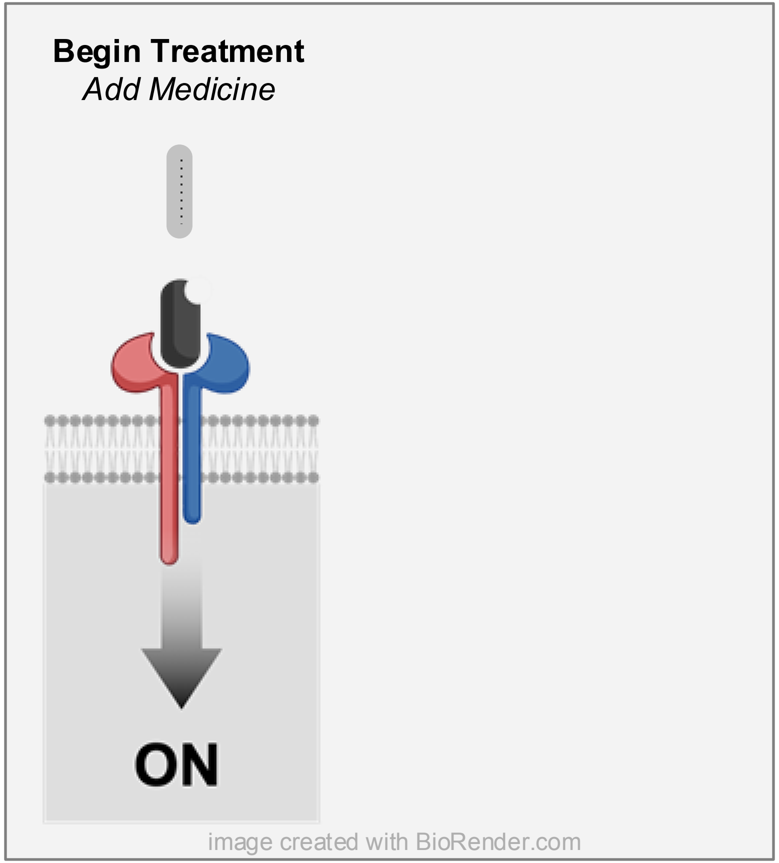




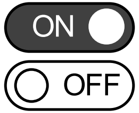
Arvind Pillai, Abbas Idris, et al. Nature, 2024

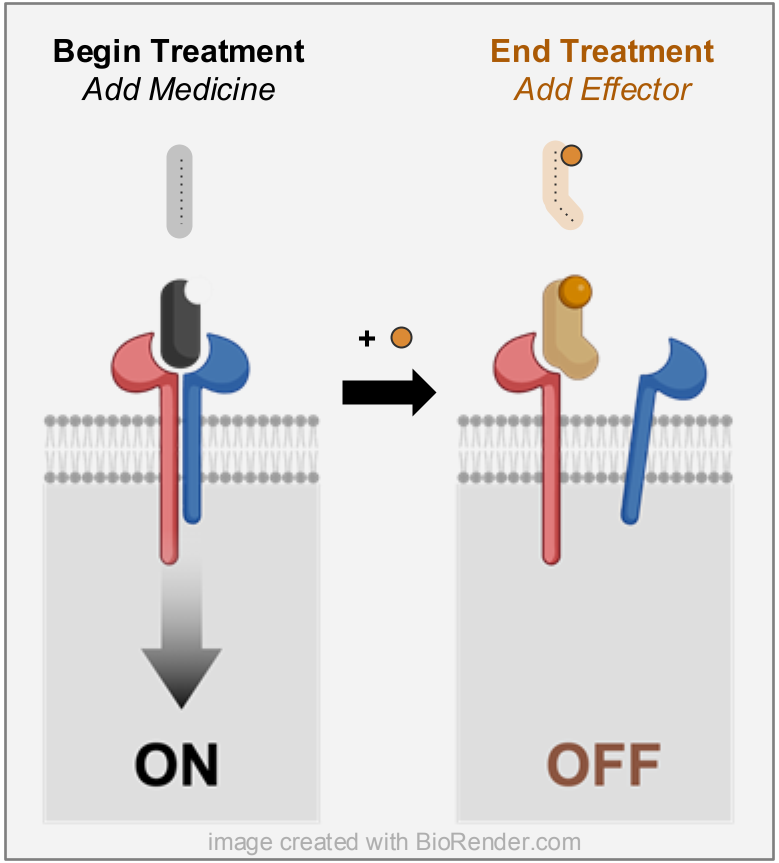


Controllable immunotherapies



Controllable immunotherapies

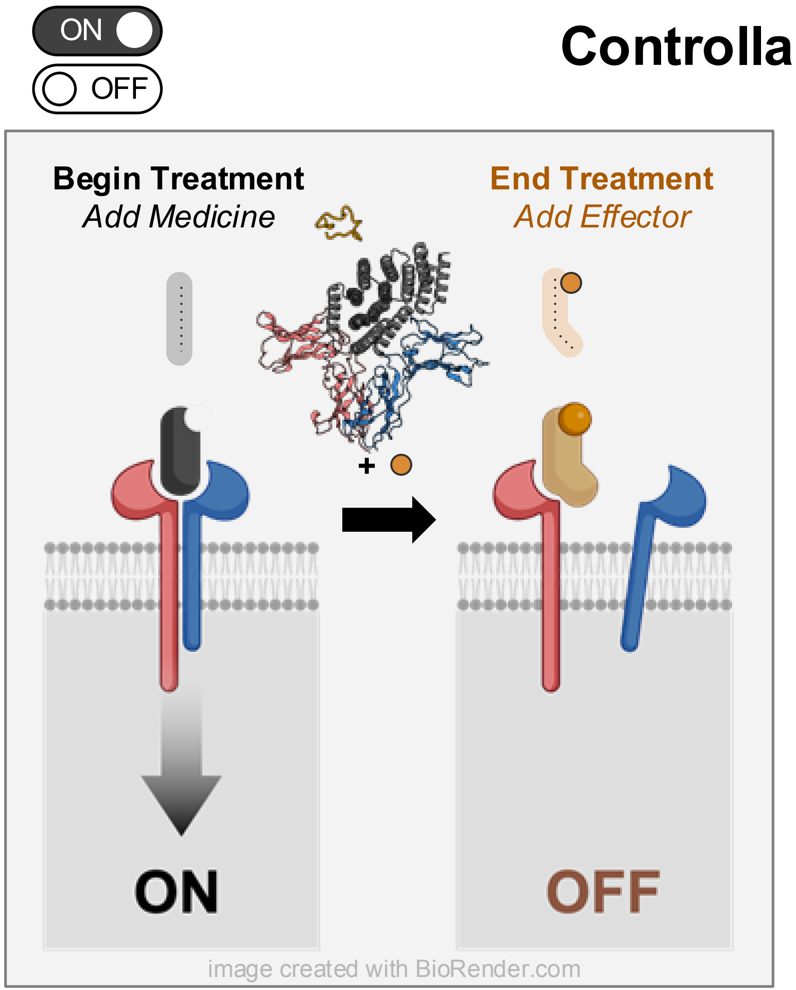




with Piehler Lab (Osnabrück U.) and Praetorius Lab (Inst. of Sci. and Tech. Austria)

Adam Broerman, Christoph Pollmann, et al. bioRxiv (preprint), 2024

Controllable immunotherapies



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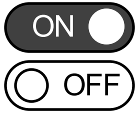
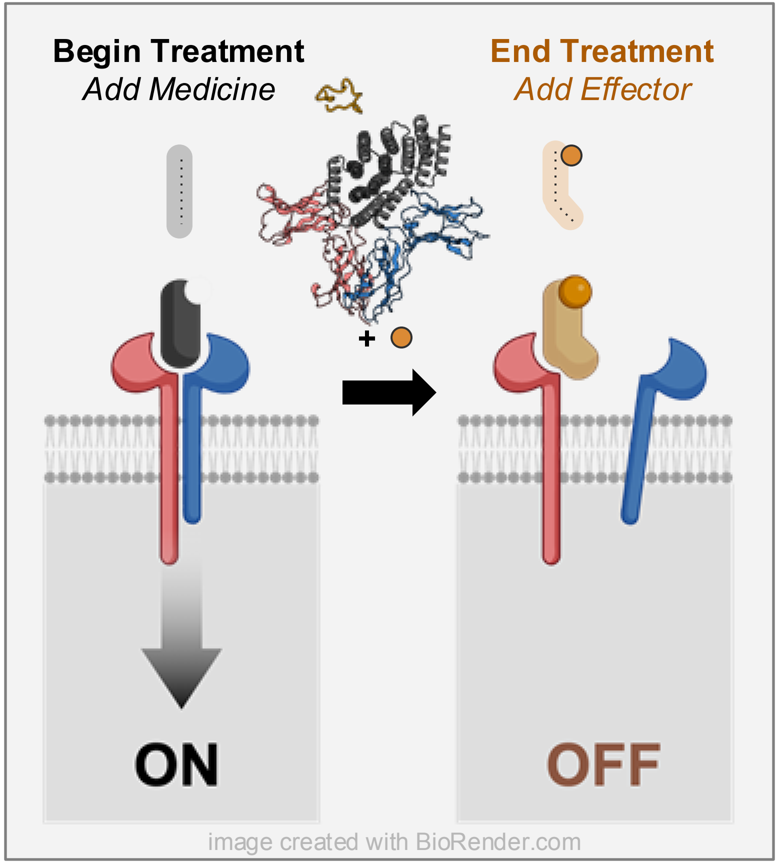
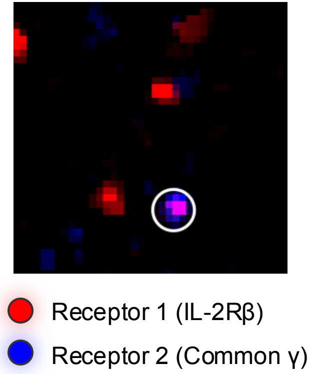
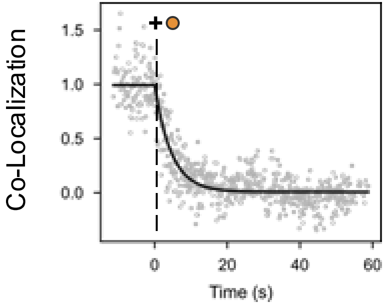


Controllable immunotherapies



Observed Co-Localization





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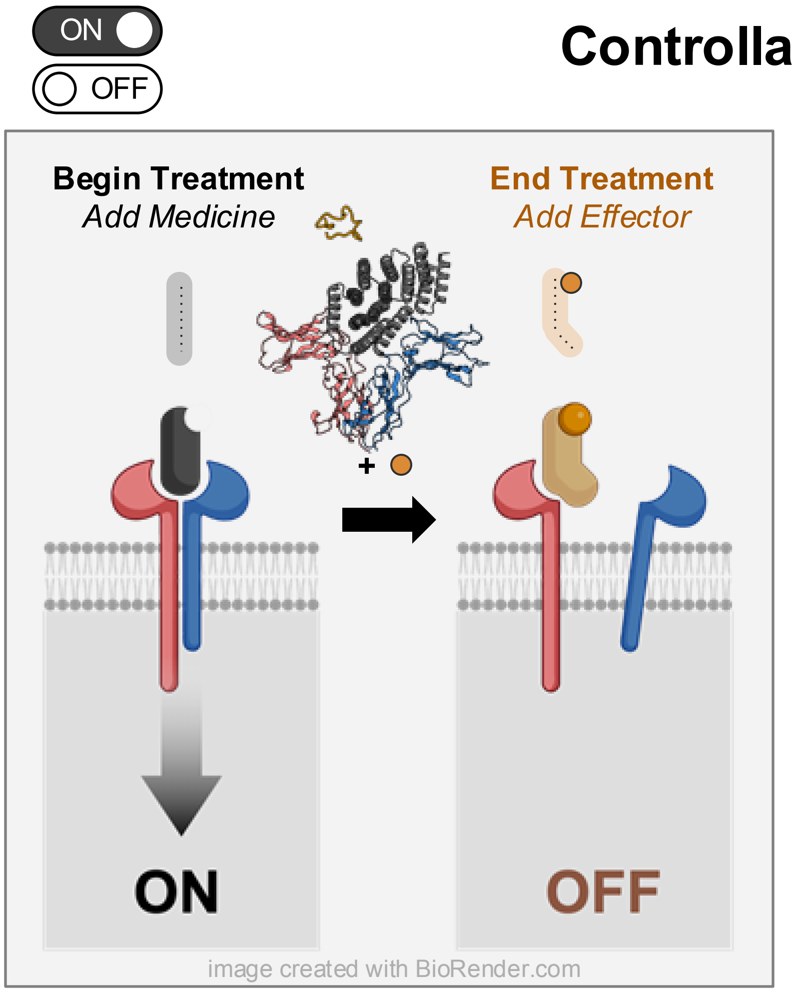
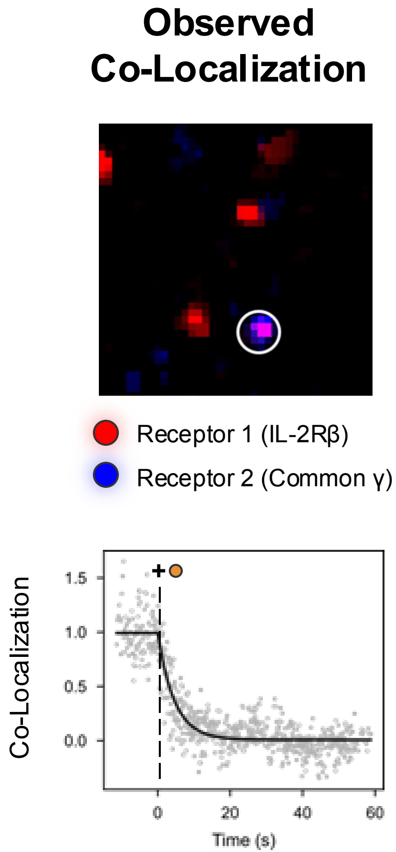
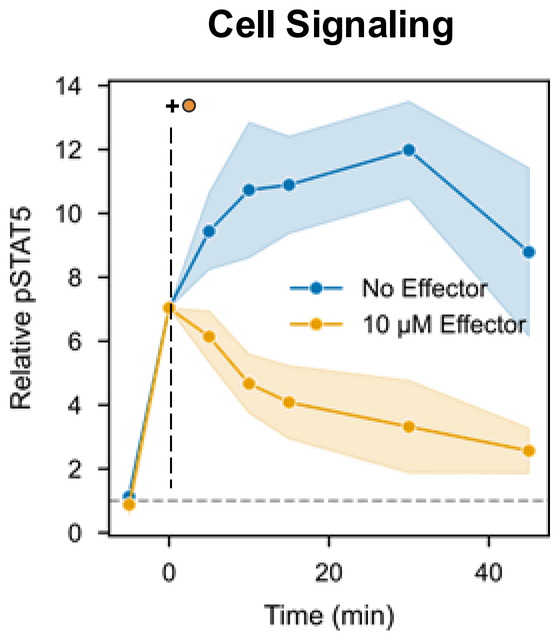
Controllable immunotherapies





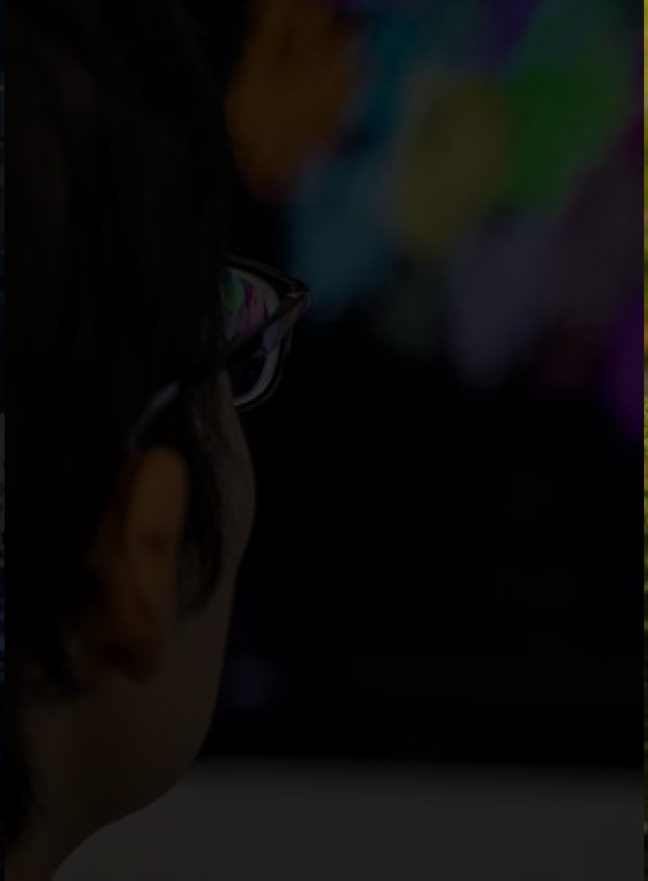


with Piehler Lab (Osnabrück U.) and Praetorius Lab (Inst. of Sci. and Tech. Austria)

Adam Broerman, Christoph Pollmann, et al. bioRxiv (preprint), 2024

Medicine

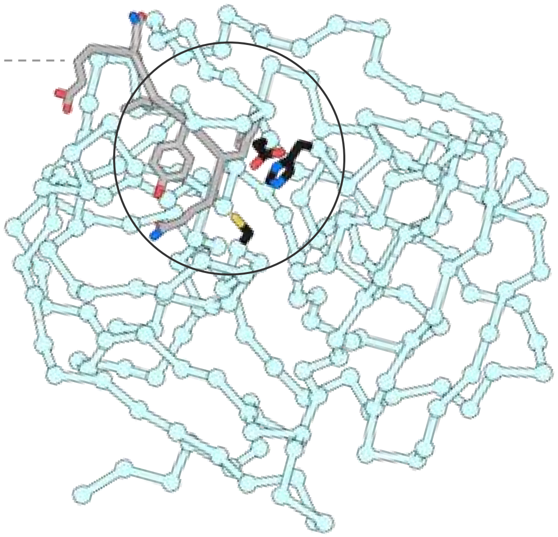
Technology



Sustainability

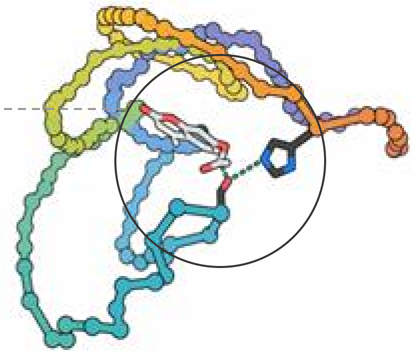
Custom catalysts

Natural Enzyme



Chemical
Substrate

Designed Enzyme

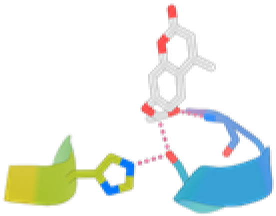


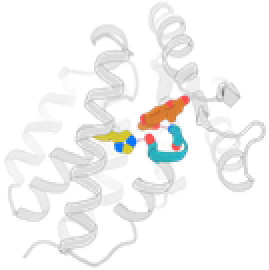
Chemical
Substrate

Building up new enzymes

1

Ser-His dyad
Oxyanion contacts: **1**





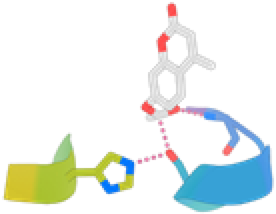
Inactive

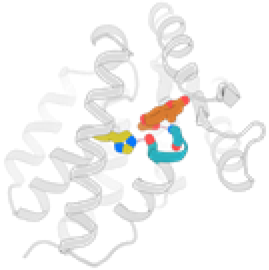
Anna Lauko, Sam Pellock, et al. bioRxiv (preprint), 2024

Building up new enzymes

1

Ser-His dyad
Oxyanion contacts: **1**

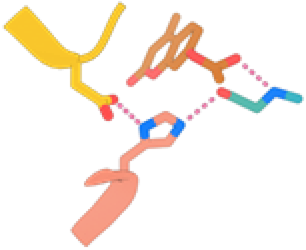


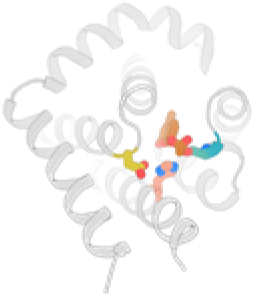


Inactive

2

Ser-His-Asp triad
Oxyanion contacts: **1**





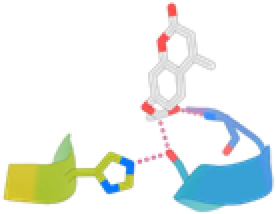
Works once… then stuck

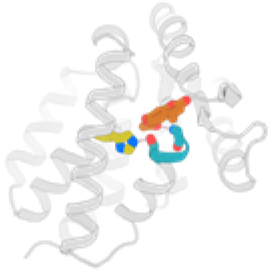
Anna Lauko, Sam Pellock, et al. bioRxiv (preprint), 2024

Building up new enzymes

1

Ser-His dyad
Oxyanion contacts: **1**

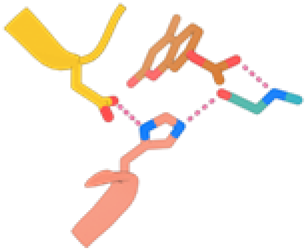


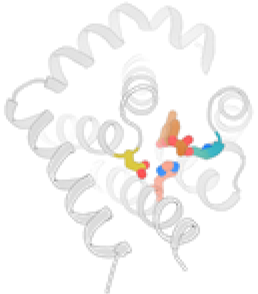


Inactive

2

Ser-His-Asp triad
Oxyanion contacts: **1**

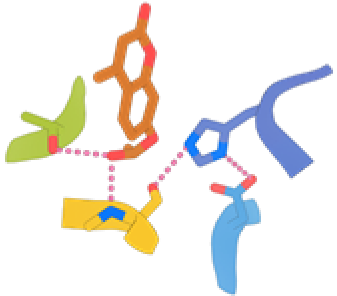


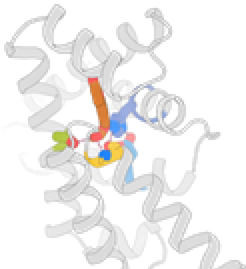


Works once… then stuck

3

Ser-His-Asp triad
Oxyanion contacts: **2**





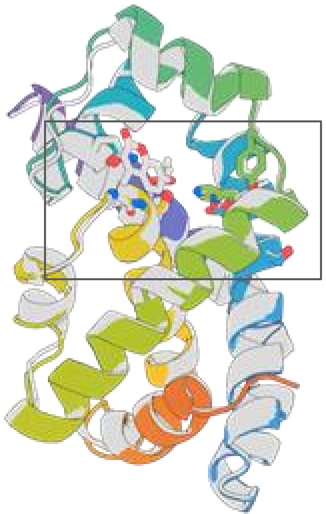
Active!

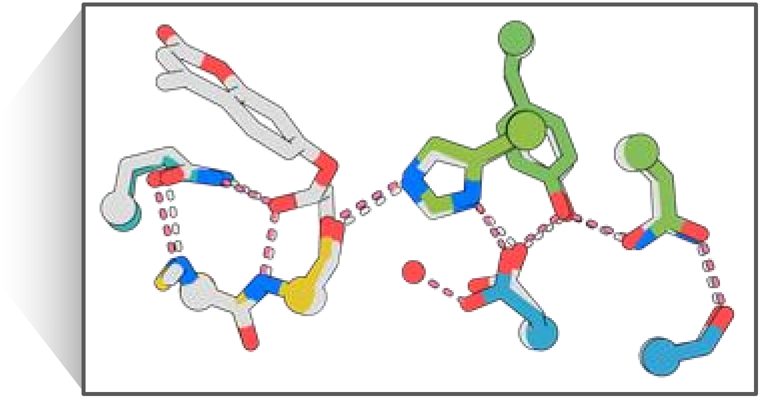
k_{cat}/K_M

3,800 $M^{-1}\ s^{-1}$

Anna Lauko, Sam Pellock, et al. bioRxiv (preprint), 2024

Building up new enzymes





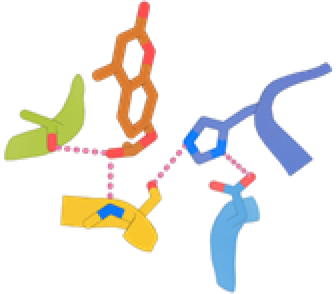
Design model

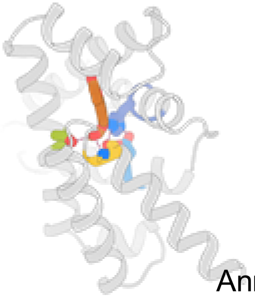
X-Ray Crystal Structure

3

Ser-His-Asp triad

Oxyanion contacts: **2**





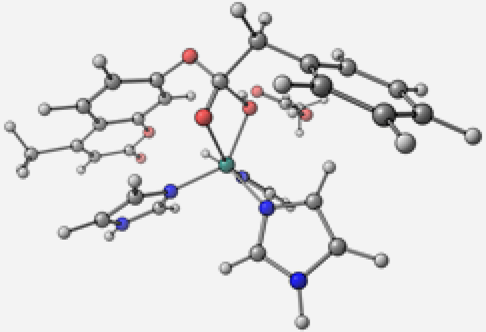
Active!

k_{cat}/K_M

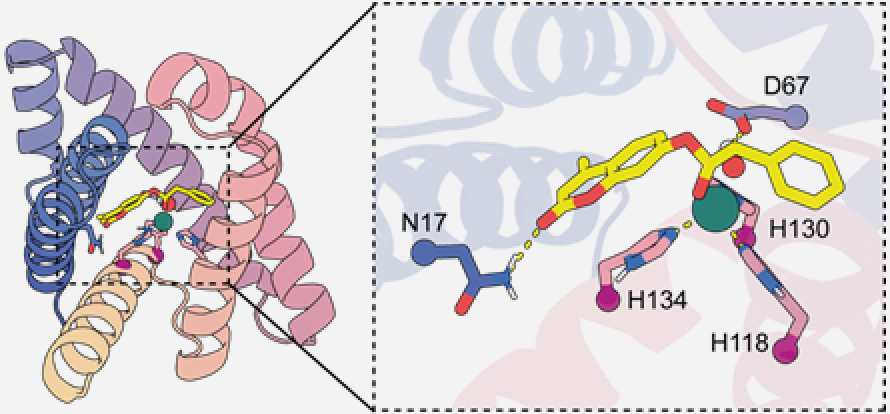
3,800 M^{-1} s^{-1}

Anna Lauko, Sam Pellock, et al. bioRxiv (preprint), 2024

Using metal to break chemical bonds

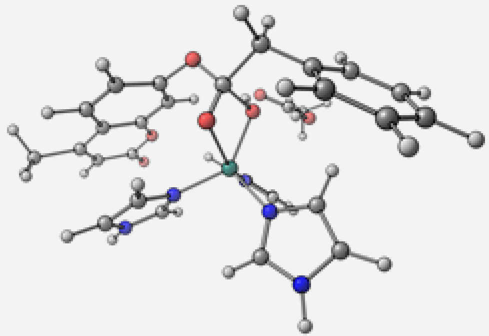


Start from quantum chemistry calculation

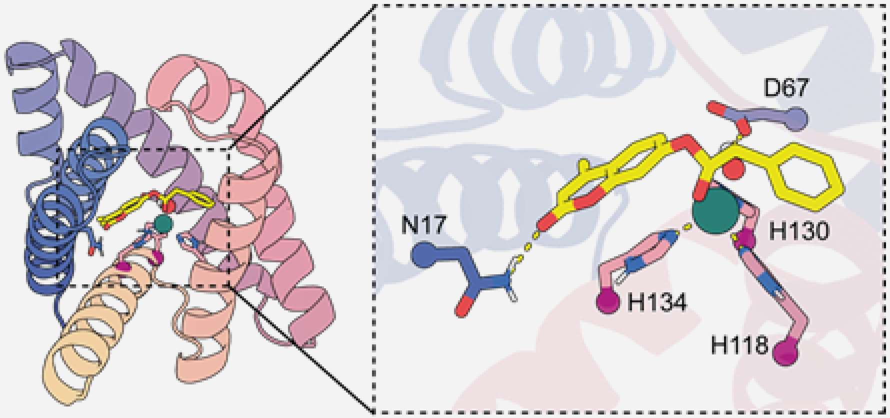


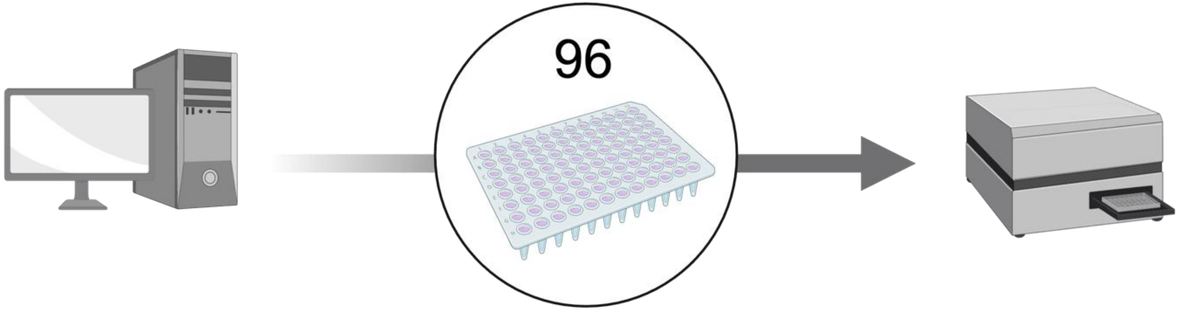
Donghyo Kim, Seth Woodbury, Woody Ahern, Indrek Kalvet, et al. bioRxiv (preprint), 2024

Using metal to break chemical bonds



Start from quantum chemistry calculation





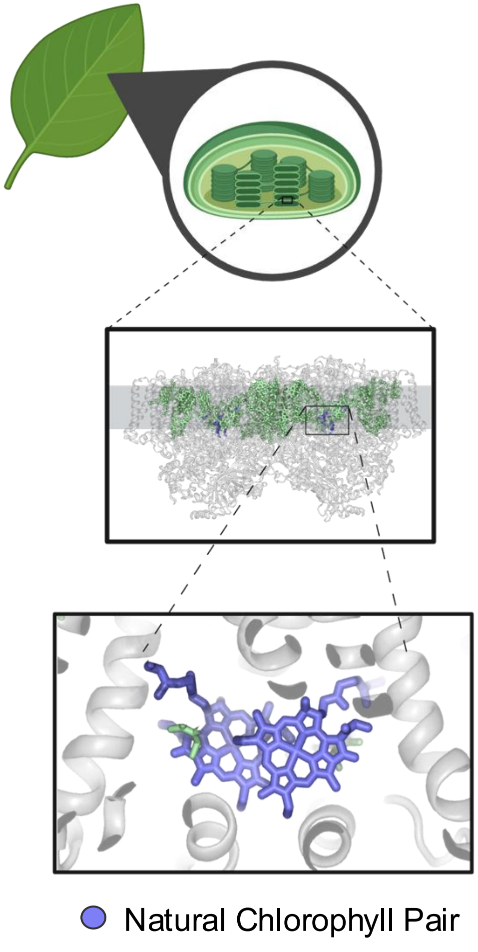
23,000 M^{-1} s^{-1}

k_{cat}/K_M

image created with BioRender.com

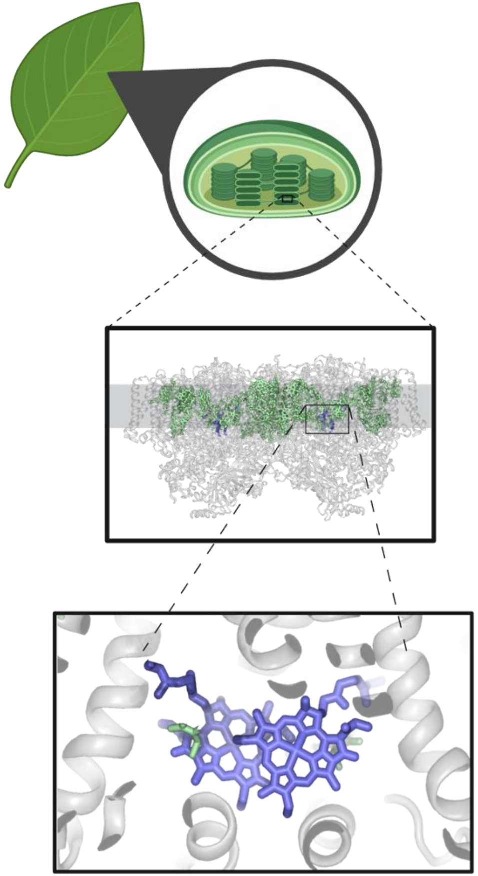
Donghyo Kim, Seth Woodbury, Woody Ahern, Indrek Kalvet, et al. bioRxiv (preprint), 2024

Harvesting sunlight

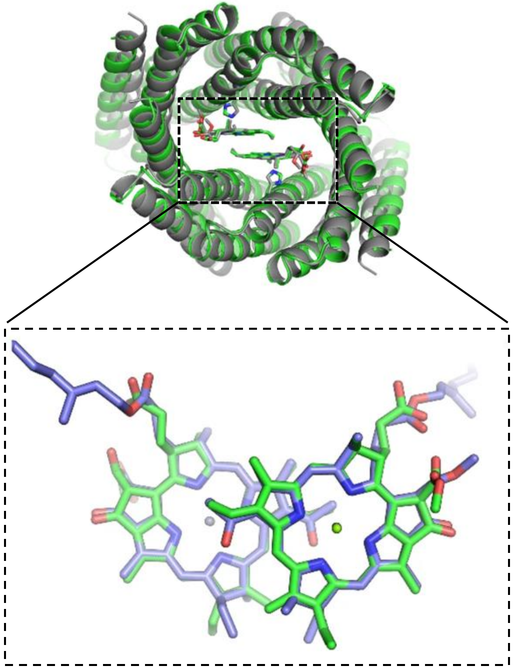


Nathan Ennist, Shunzhi Wang, et al. Nature Chemical Biology, 2024

Harvesting sunlight



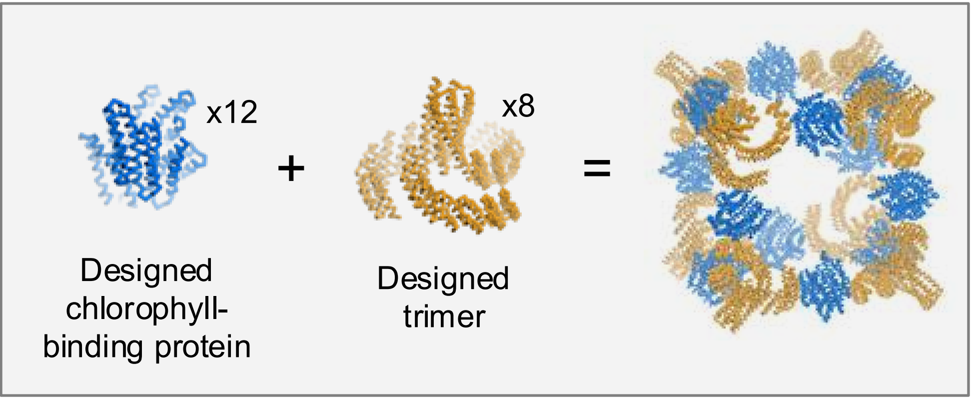
Natural Chlorophyll Pair

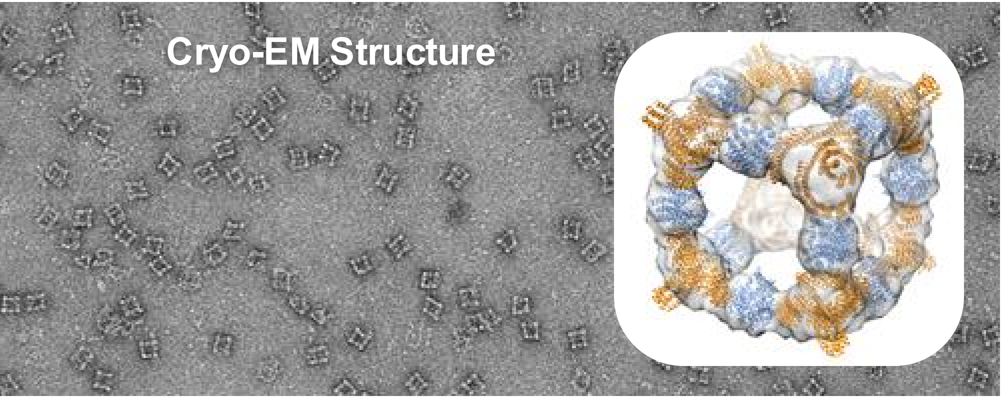


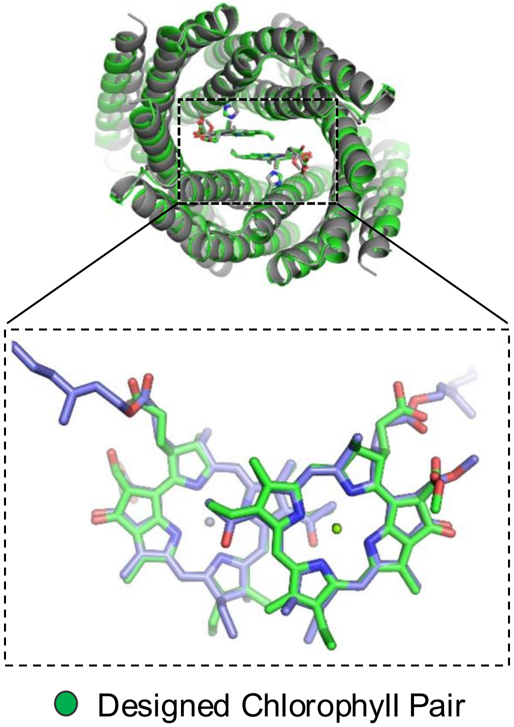
Designed Chlorophyll Pair

Nathan Ennist, Shunzhi Wang, et al. Nature Chemical Biology, 2024

Harvesting sunlight

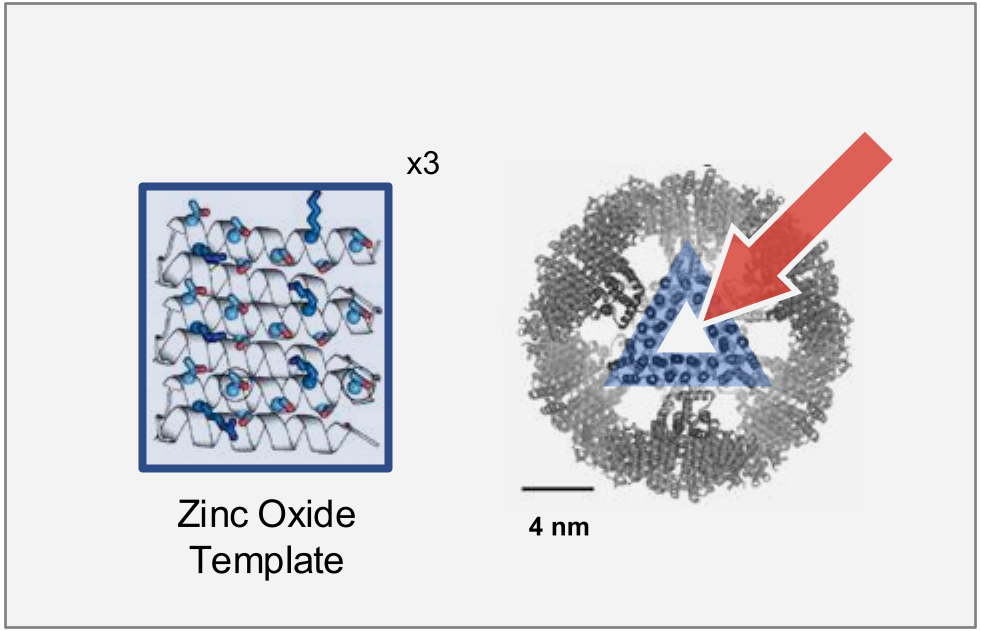






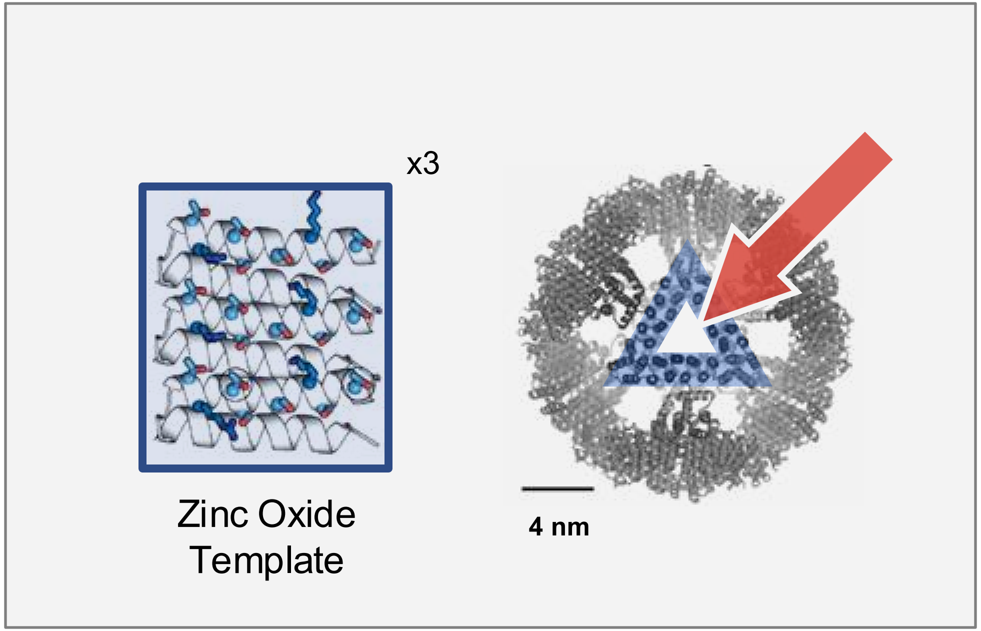
Nathan Ennist, Shunzhi Wang, et al. Nature Chemical Biology, 2024

Growing semiconductors

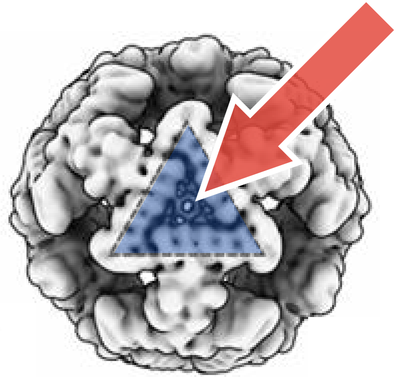


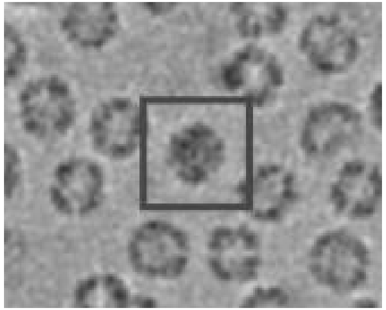
Amijai Saragovi, Harley Pyles, et al. bioRxiv (preprint), 2024

Growing semiconductors



Cryo-EM Structure
with Zinc Oxide





Amijai Saragovi, Harley Pyles, et al. bioRxiv (preprint), 2024

A whole new world of designed proteins

Medicine

Pandemic Preparedness
Cancer & Immunotherapy
Neurodegeneration

Technology

Chemical Sensors
Bio-Electronic Devices
Drug Delivery

Sustainability

Breaking Down Plastic
Artificial Photosynthesis
Nanoscale Manufacturing