

Advanced X-Ray Light Sources for Frontier Life Science Research

Recent Advances in Life Sciences

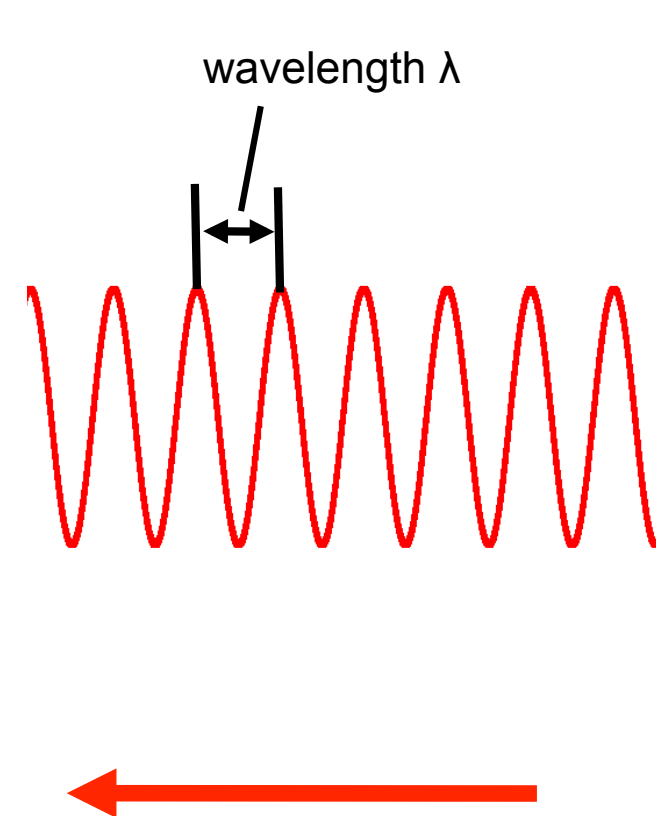
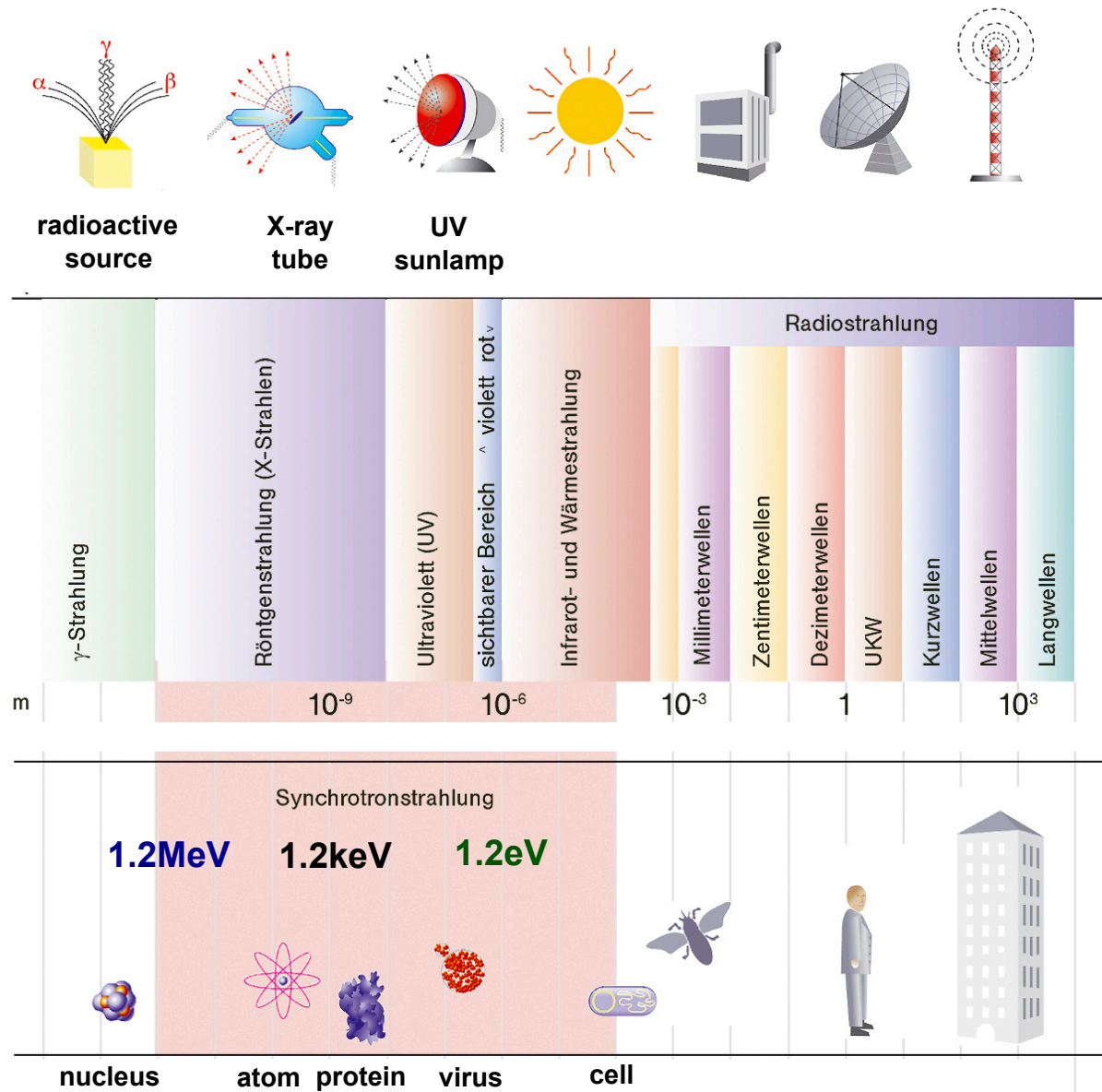


Outline



- **Introduction**
 - What are X-rays ?
 - How to generate X-rays ?
 - Modern sources for X-rays
- **Applications in life-science**
 - Imaging of organism
 - Structure of biomolecules
 - Function of biomolecules
- **Outlook**
 - Dream of many structural biologist

What are X-rays ? Electromagnetic waves

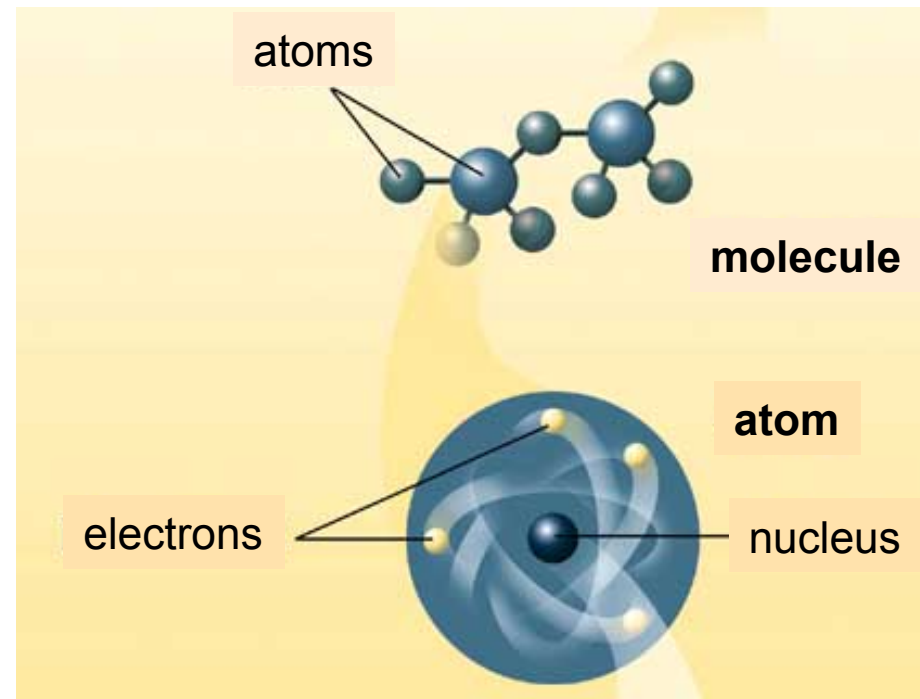
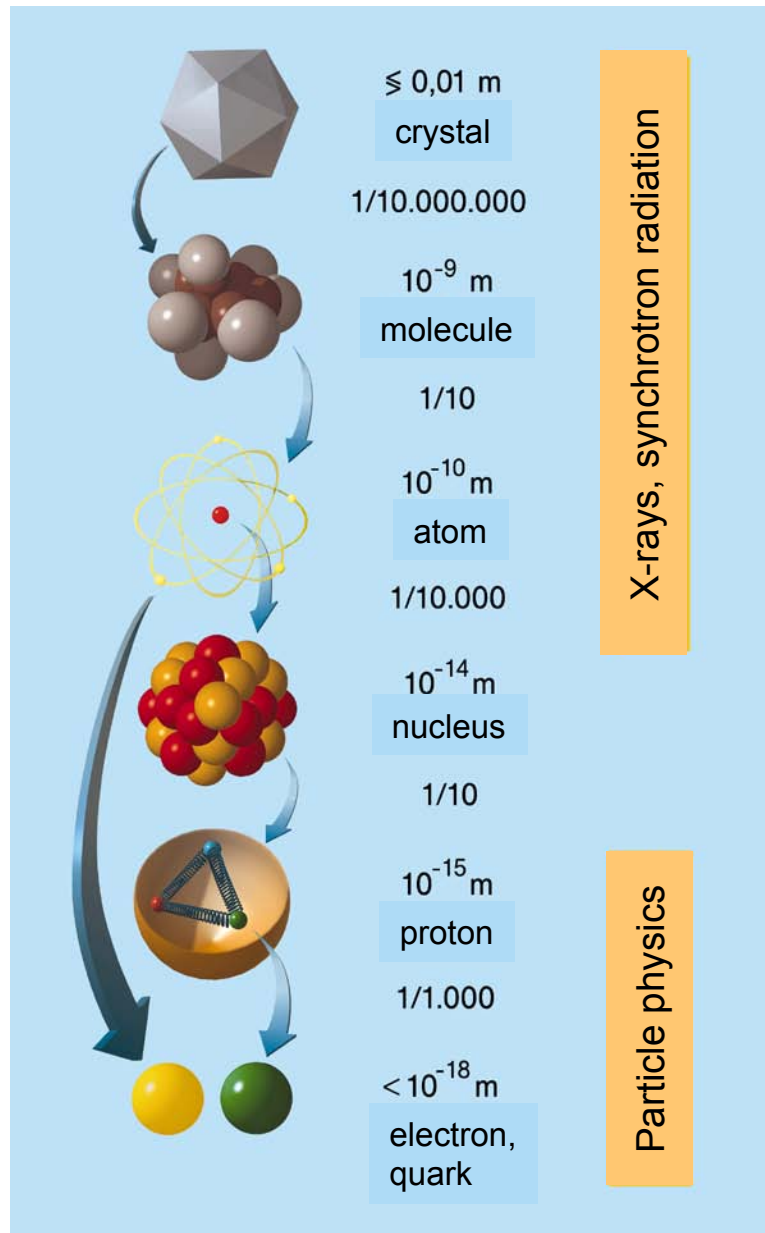


Photon energy

radiation **photon energy**
hard **high (X-rays)**
soft **low (UV-VUV)**



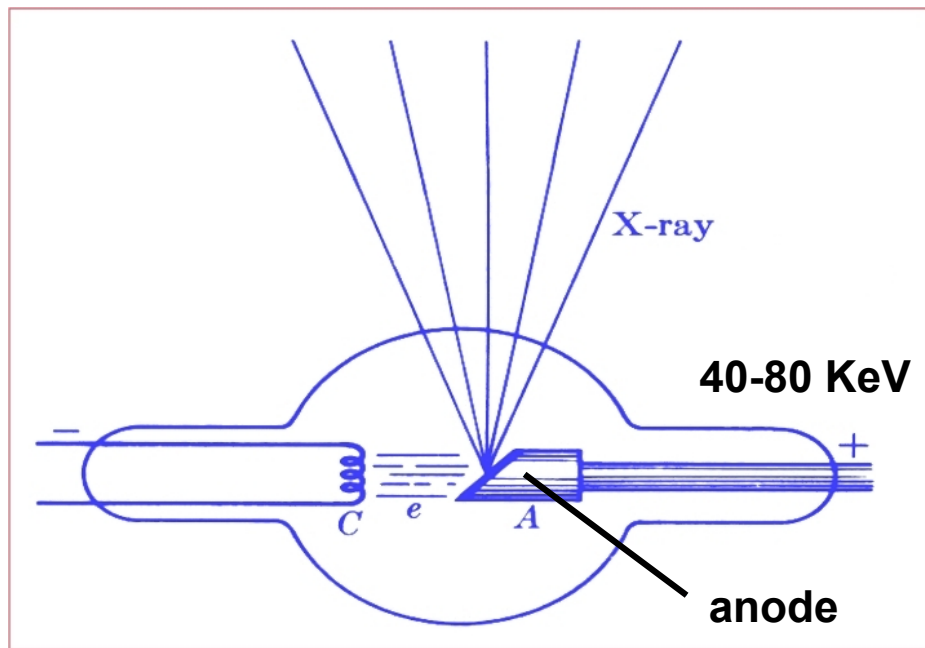
Structure of matter



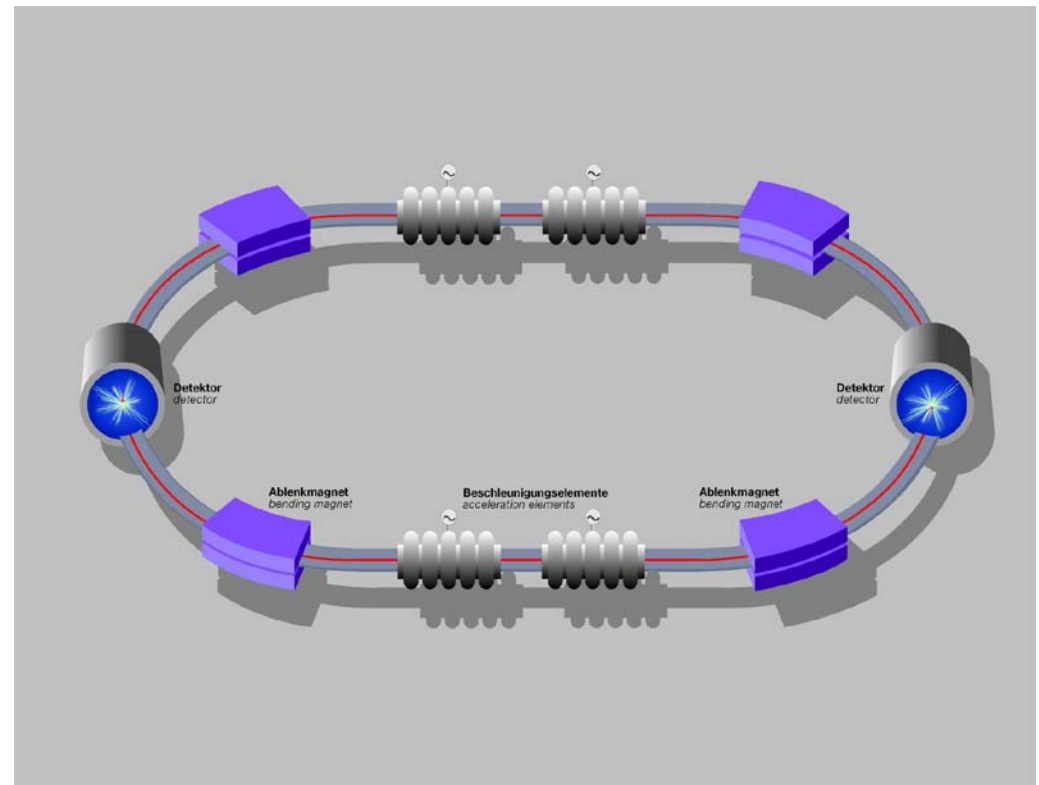
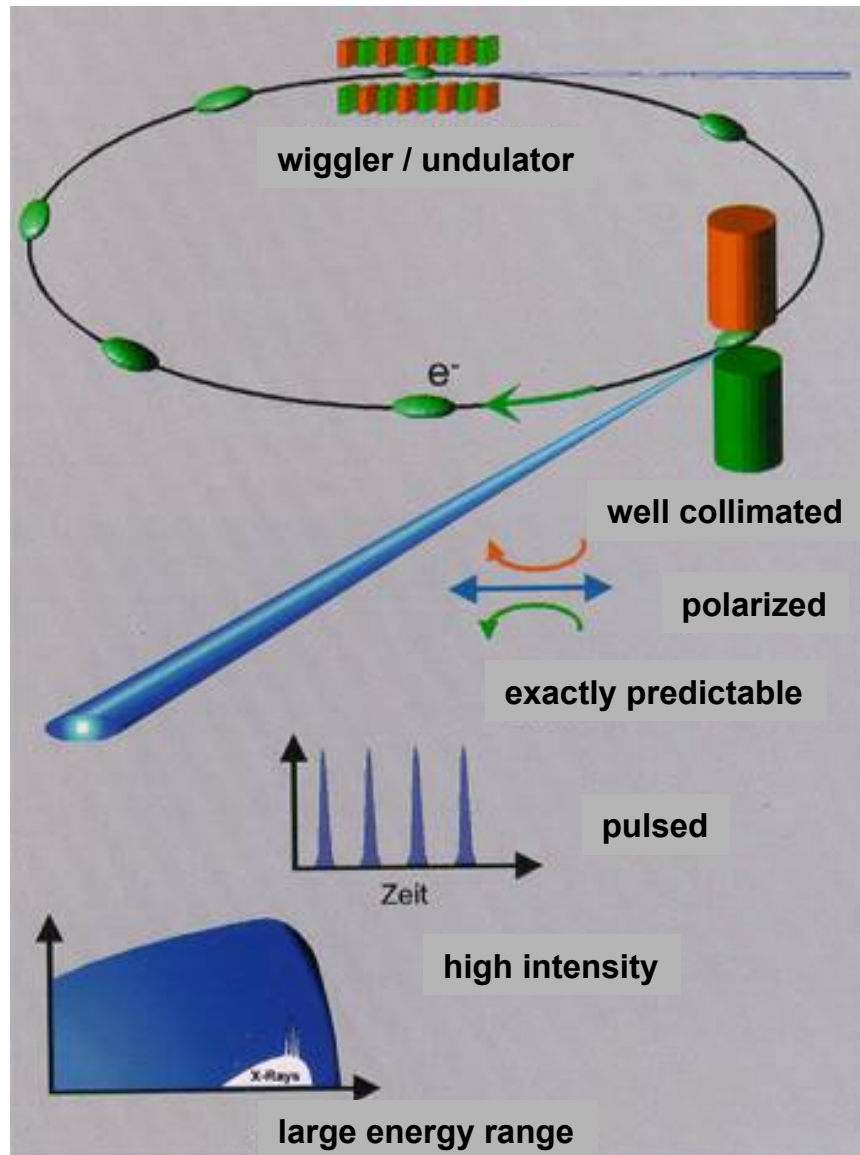
X-rays



Discovered by
Wilhelm Conrad Röntgen
in the year 1895 in
Würzburg, Germany

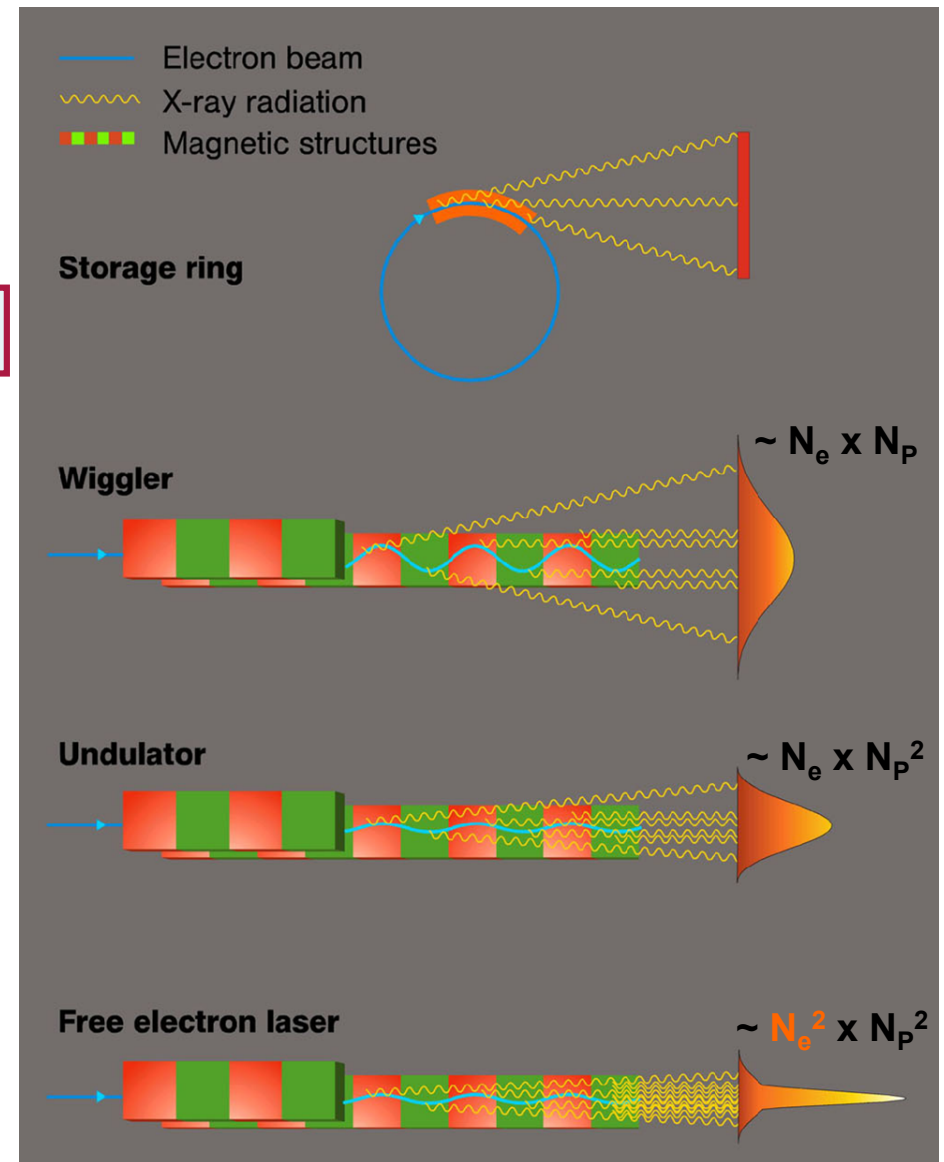
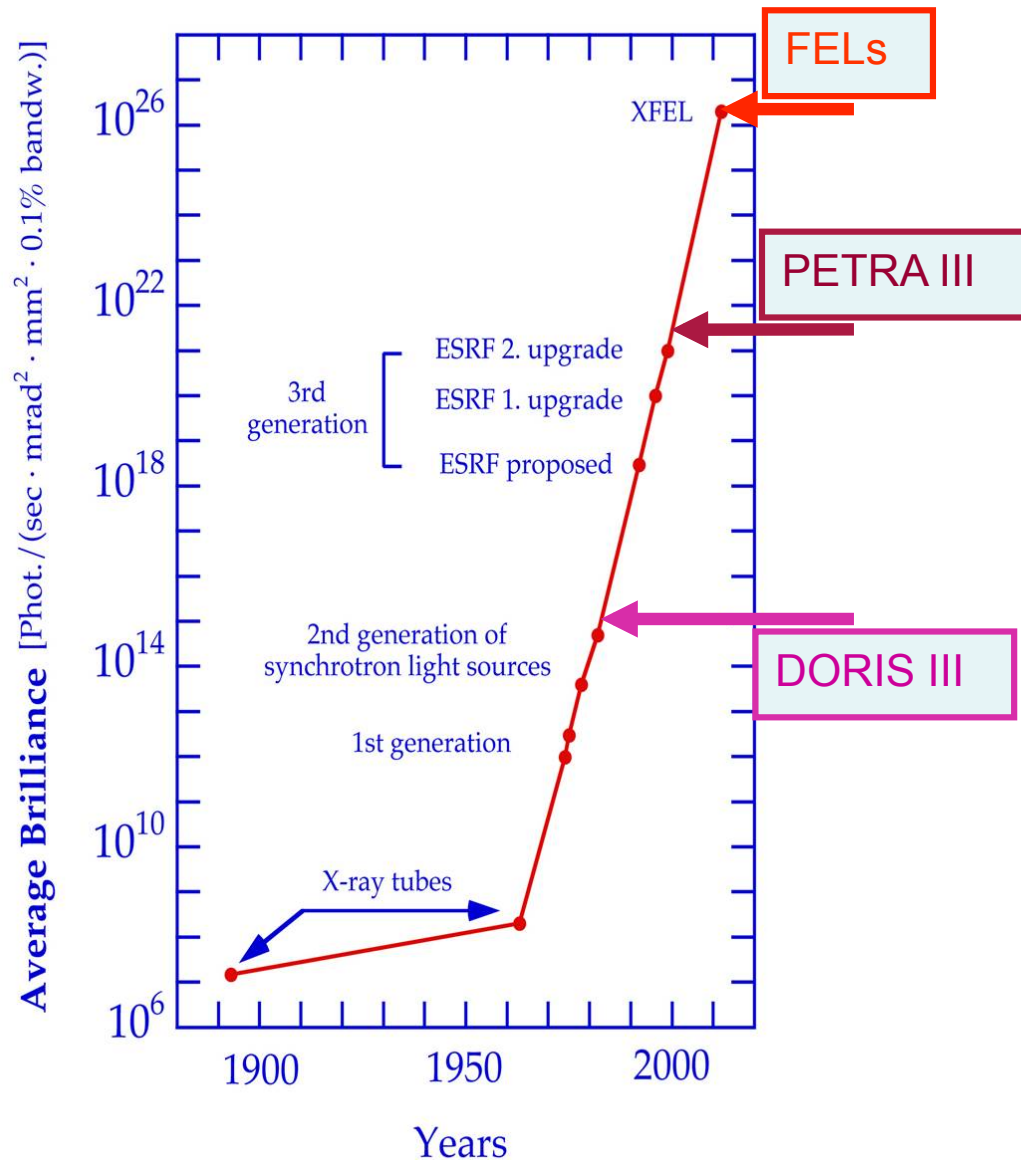


Generation of synchrotron radiation

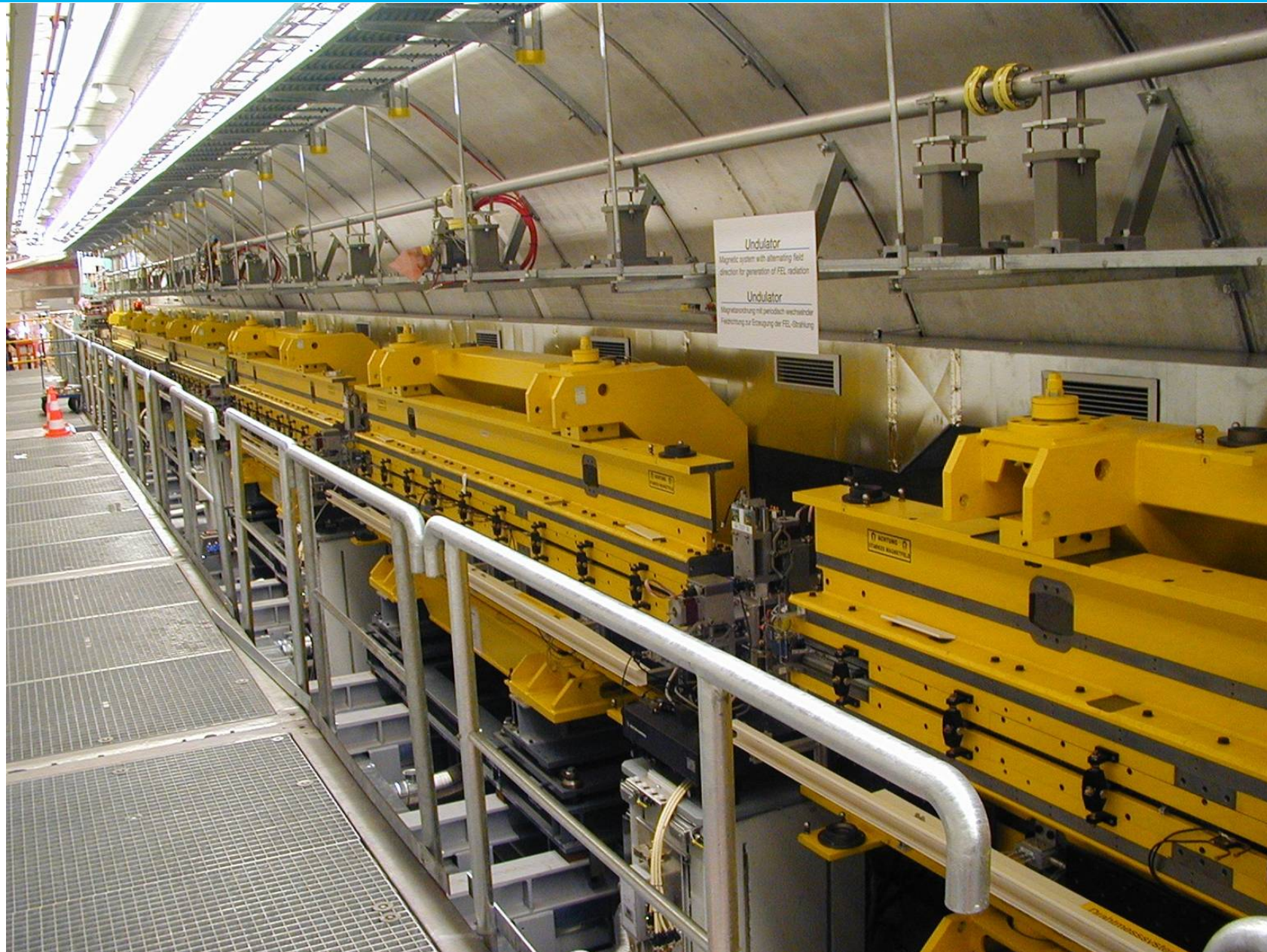


Principle of a ring accelerator

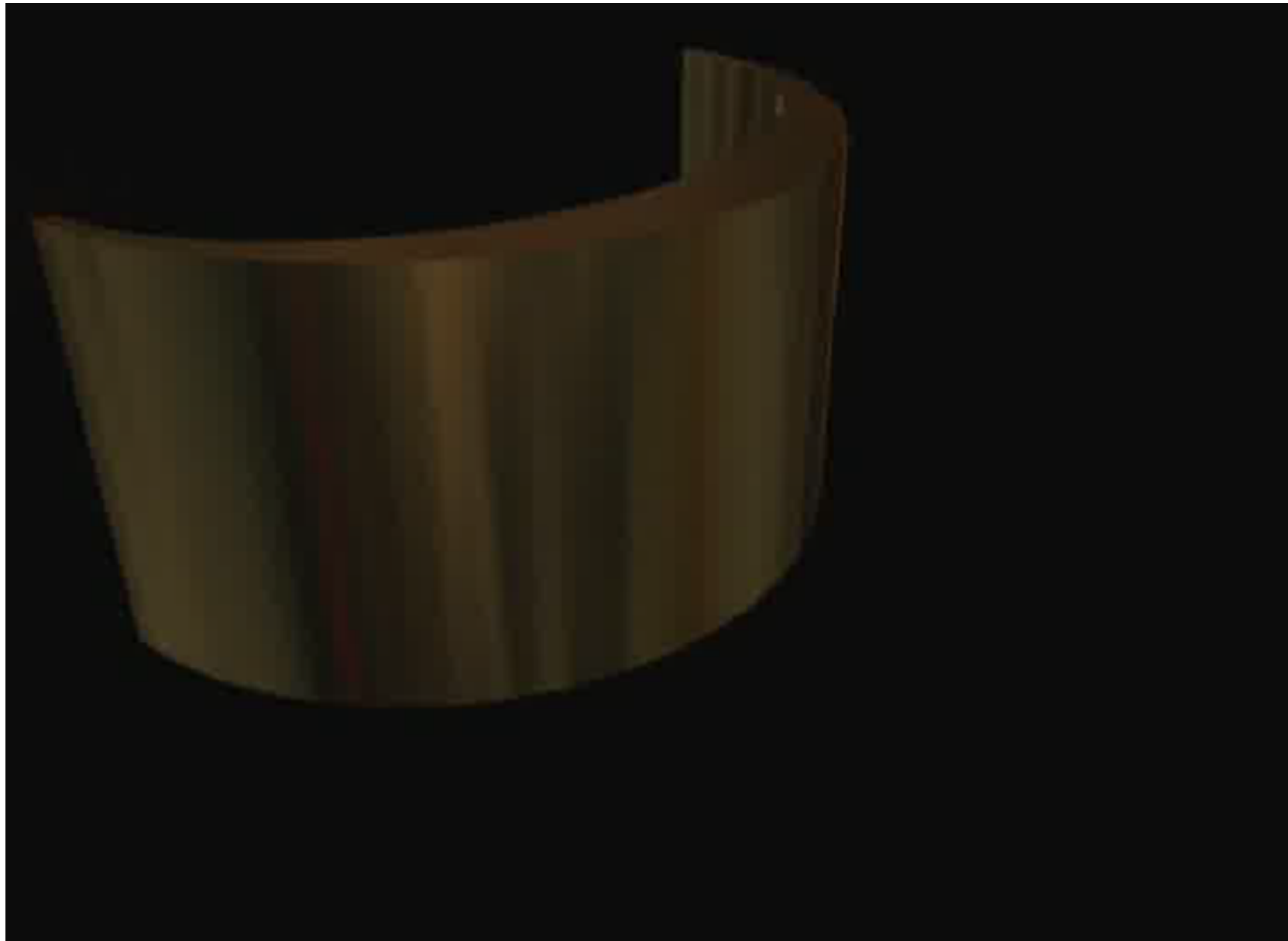
Properties of synchrotron radiation



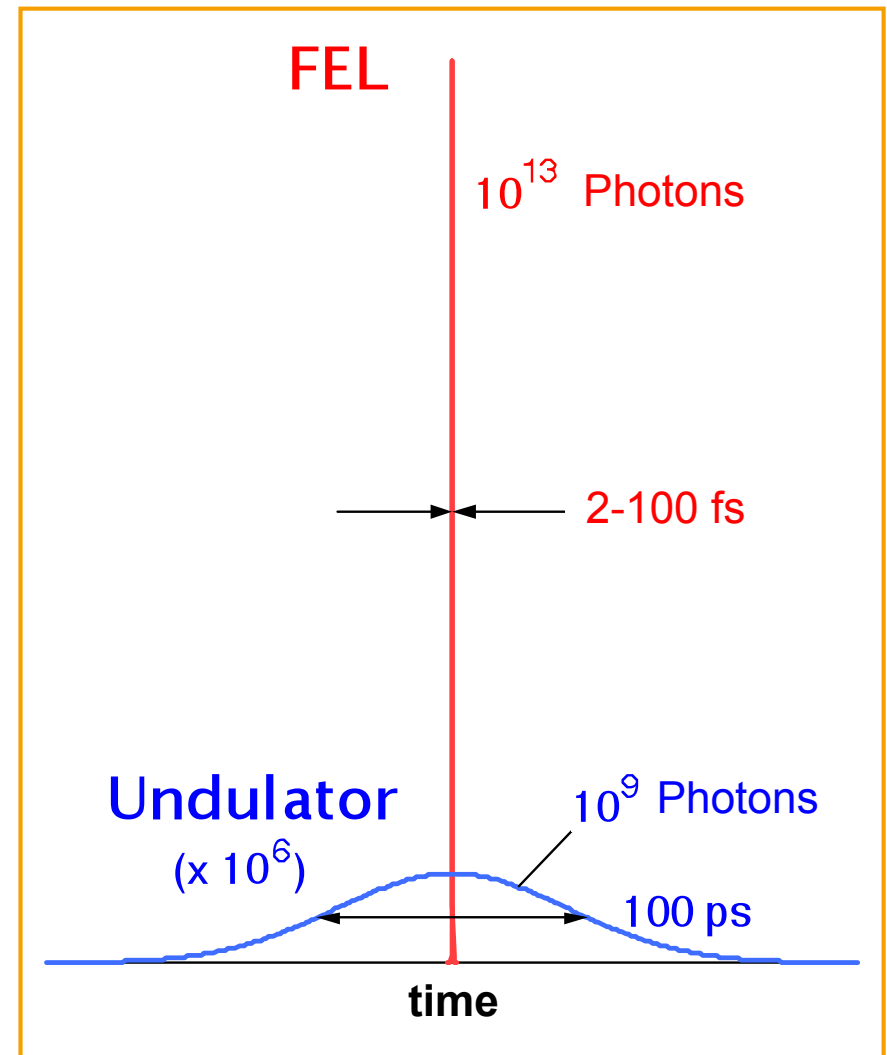
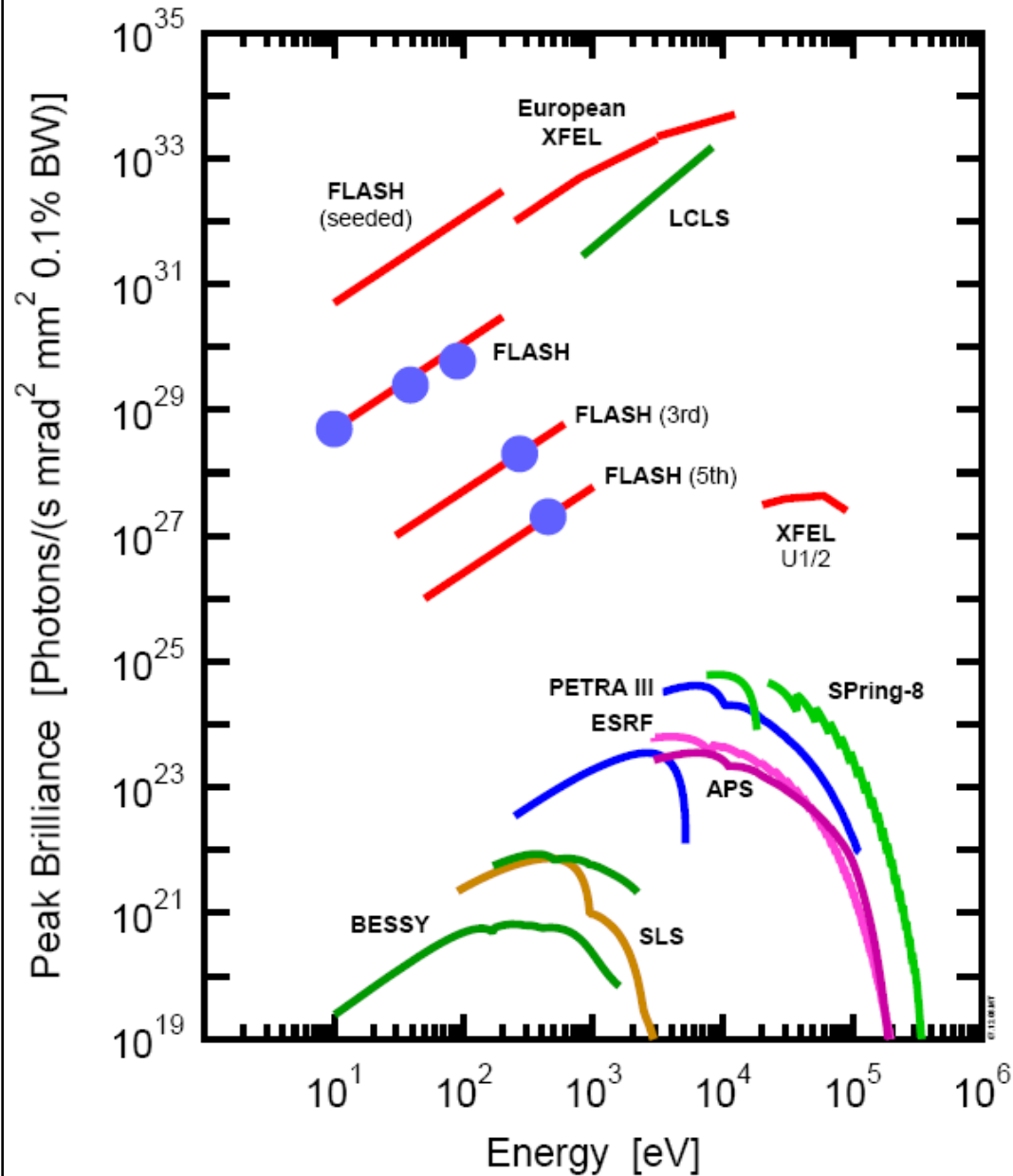
Wigglers and undulators



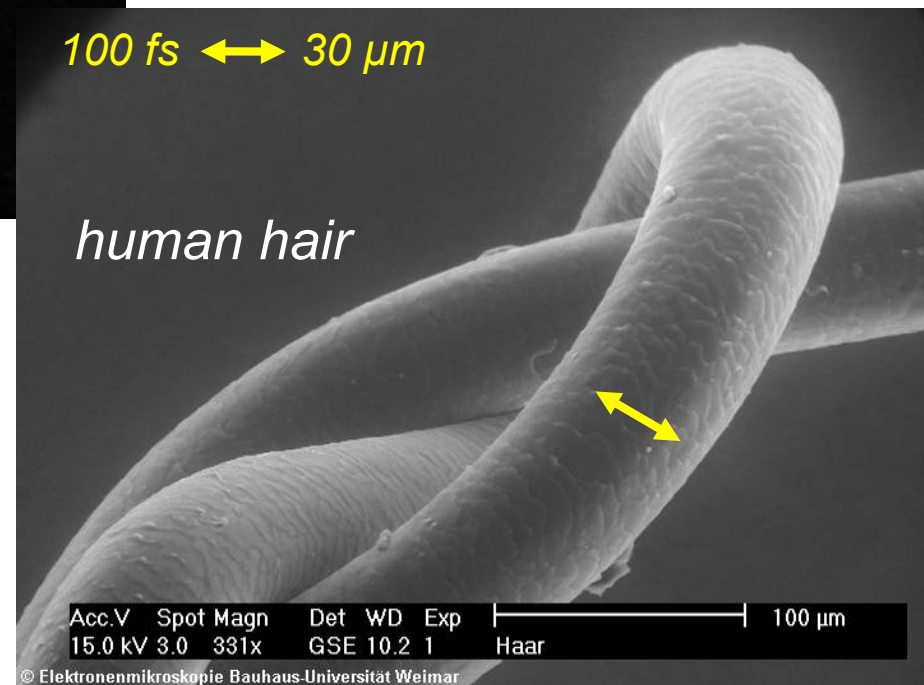
Generation of FEL radiation



Properties of FEL radiation



How long is 100 fs ??



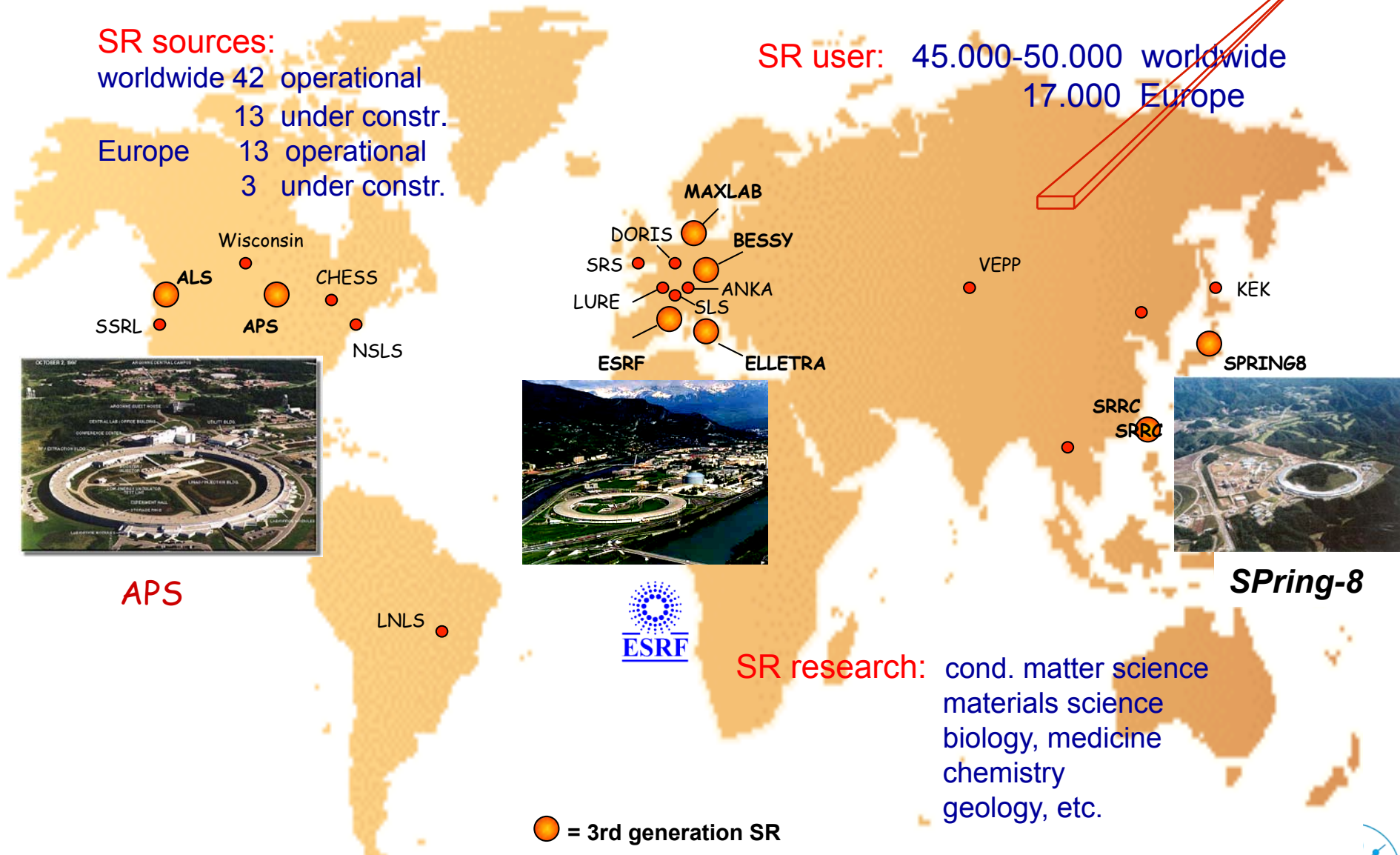
Synchrotron radiation sources world wide



SR sources:

worldwide 42 operational
13 under constr.
Europe 13 operational
3 under constr.

SR user: 45.000-50.000 worldwide
17.000 Europe



PETRA III: new high energy 3rd generation source



- rebuild of **1/8** of the **2304m** circumference
- refurbishment of 7/8 of the storage ring
- refurbishment of pre-accelerator chain
(also used by DORIS III)
- construction of a **300m** long new experimental hall
- installation of **80m** of **damping wigglers**
- top up operation mode

key parameters:

- **particle energy:** **6GeV**
- **current:** **100mA (200mA)**
- **horizontal emittance:** **1 nmrad**
- **No. of undulators:** **14 (incl. canted)**
- **undulator lengths:** **2-10(20) m**
- **no bending magnet beamlines**



FLASH



1,2 GeV Electrons
60-4.4 nm X-ray laser
20 fsec flashes



HELMHOLTZ
| GEMEINSCHAFT

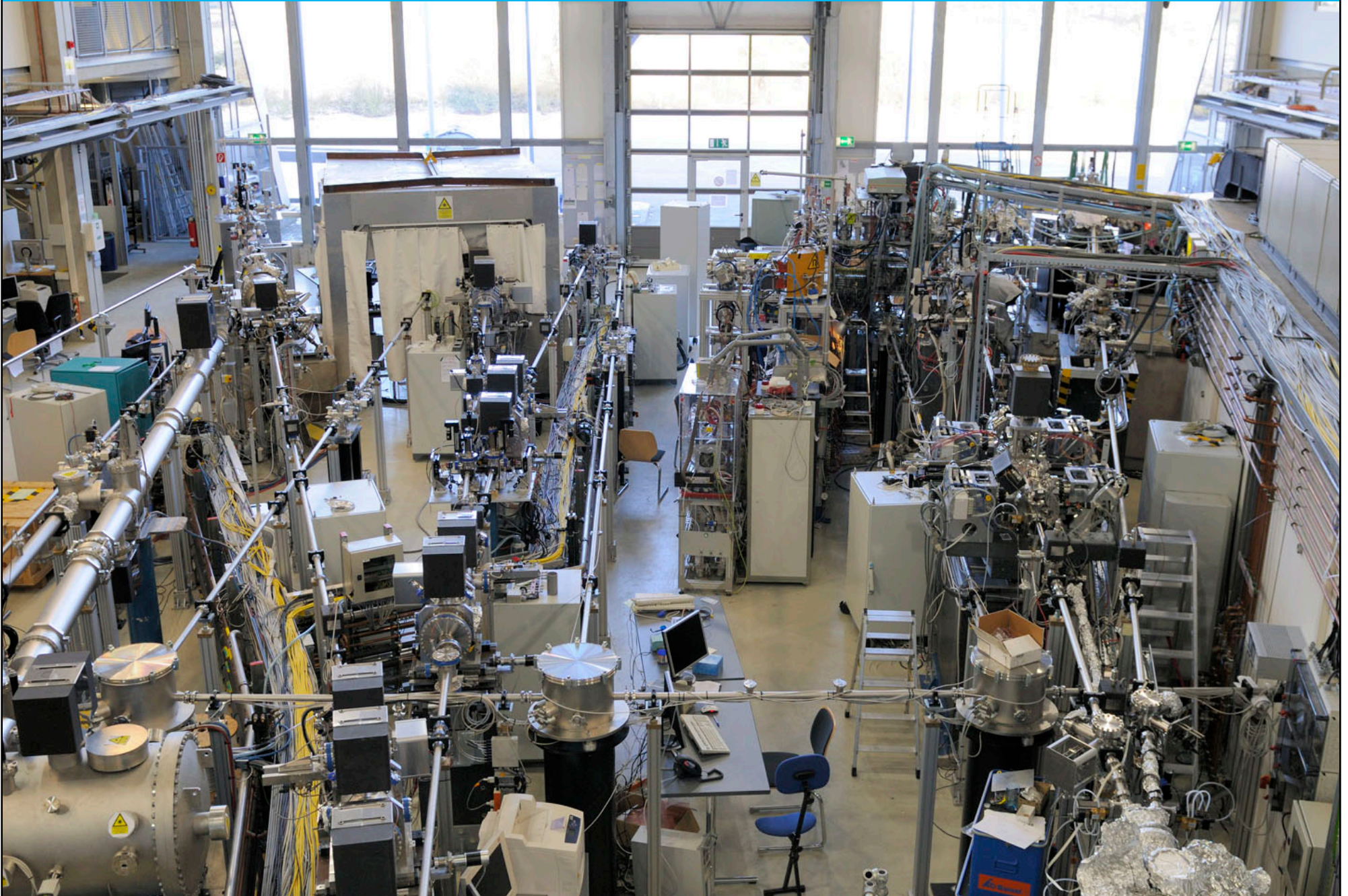


FLASH II

Seeded FEL



FLASH overview



Linac Coherent Light Source at SLAC

X-FEL based on last 1-km of existing linac

1.5-15 Å

Injector (35°)
at 2-km point

Existing 1/3 Linac (1 km)
(with modifications)

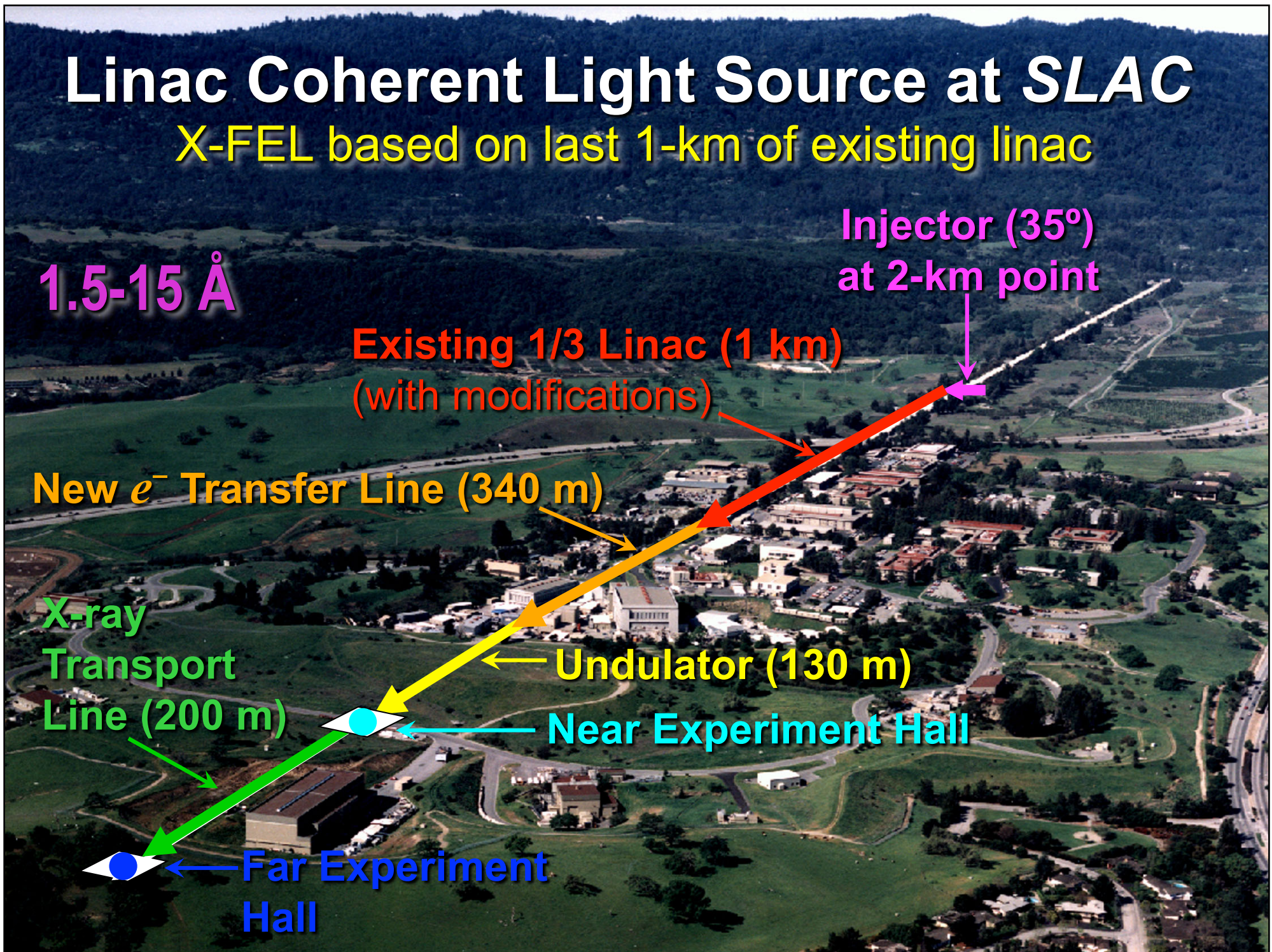
New e^- Transfer Line (340 m)

X-ray
Transport
Line (200 m)

Undulator (130 m)

Near Experiment Hall

Far Experiment
Hall



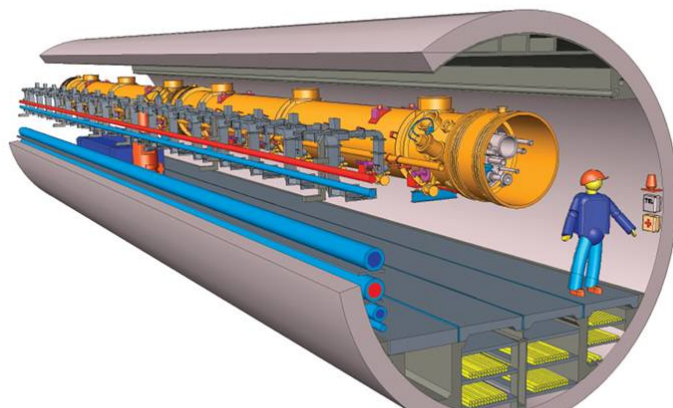
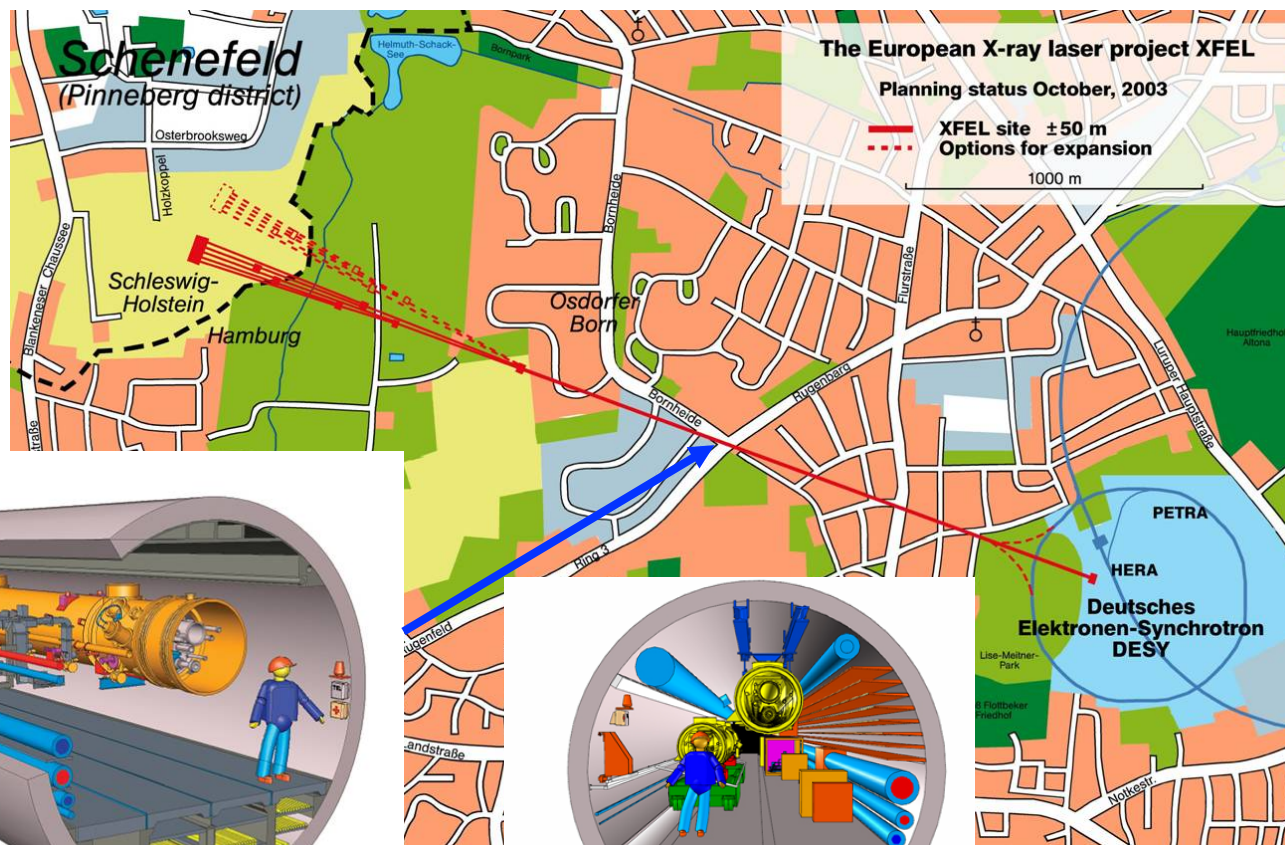
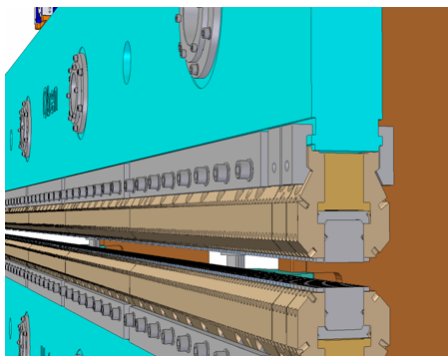
SCCS@Spring-8, Japan





European XFEL

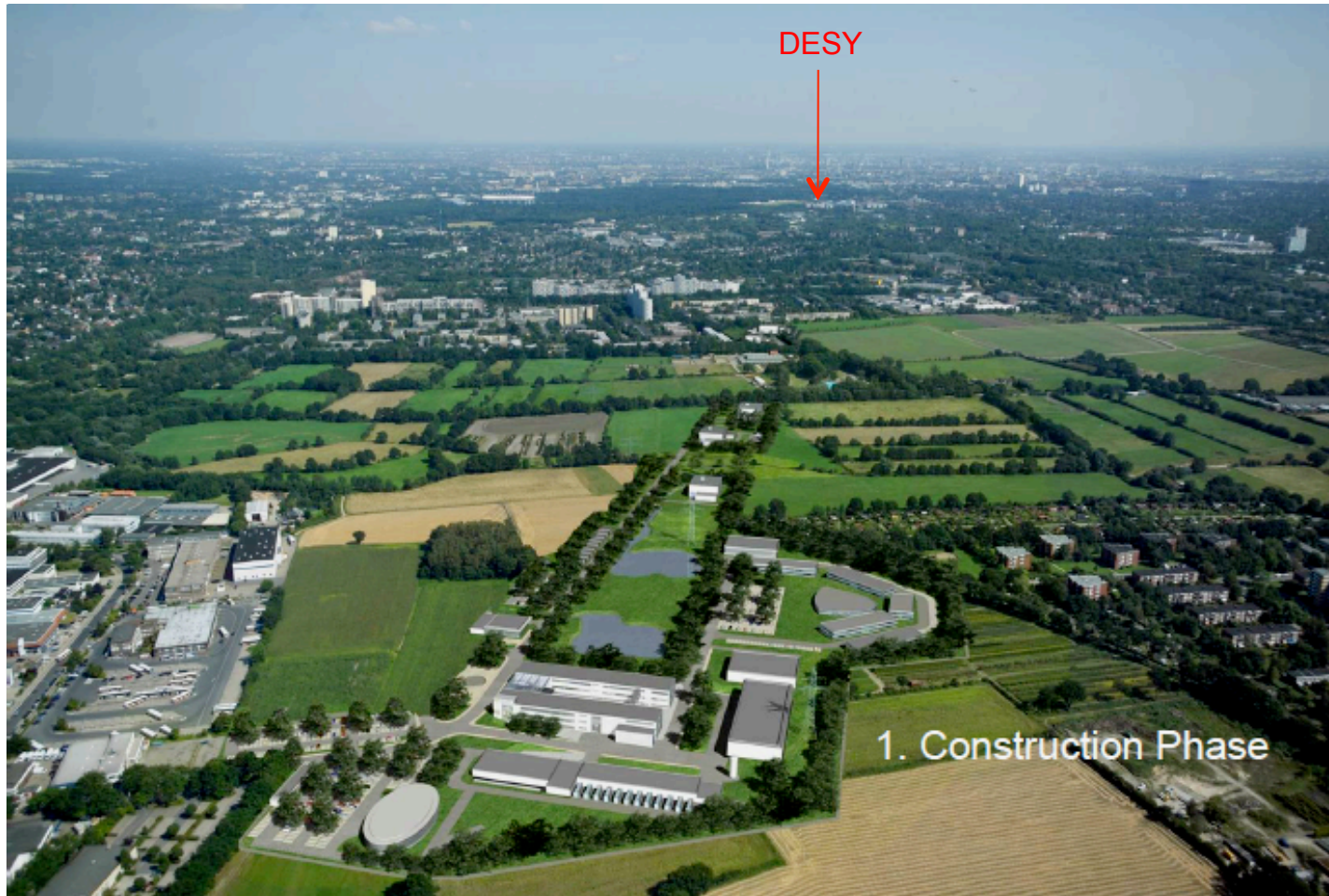
← 3.4km →



CH CN DE DK ES FR GB GR HU IT PL RU SE



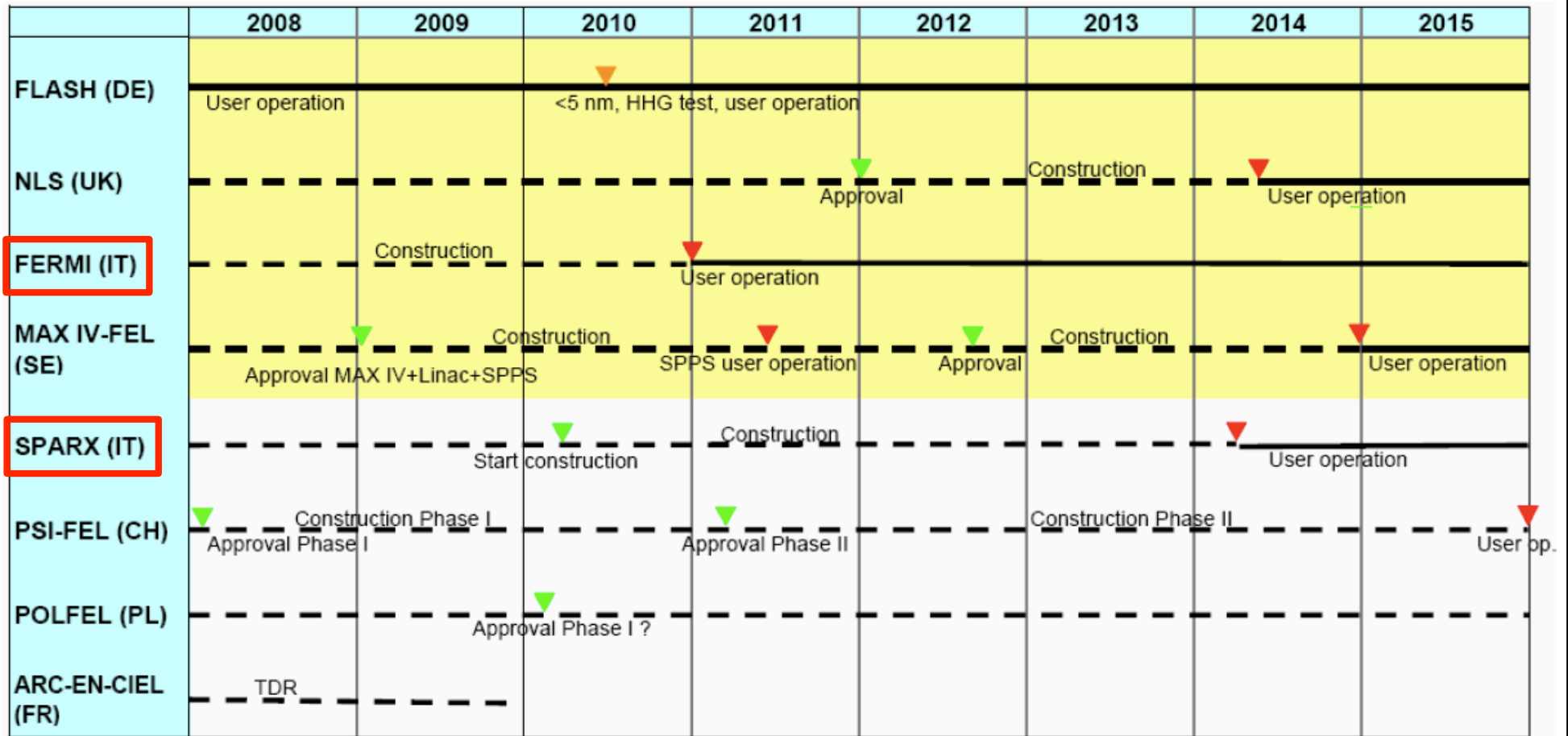
European XFEL



European XFEL construction sites



Other FEL projects in Europe

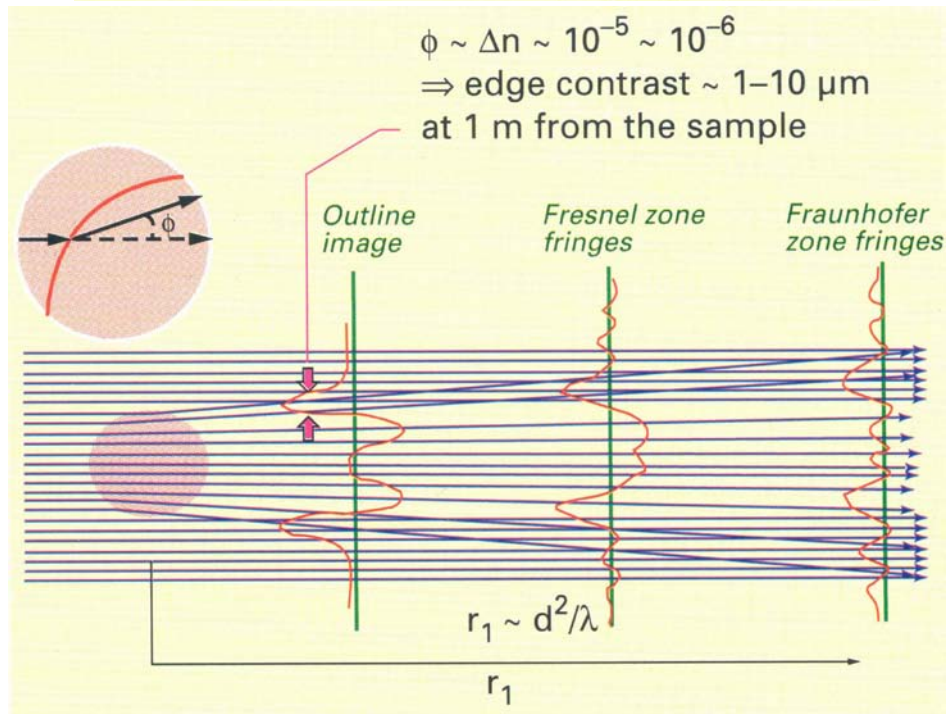
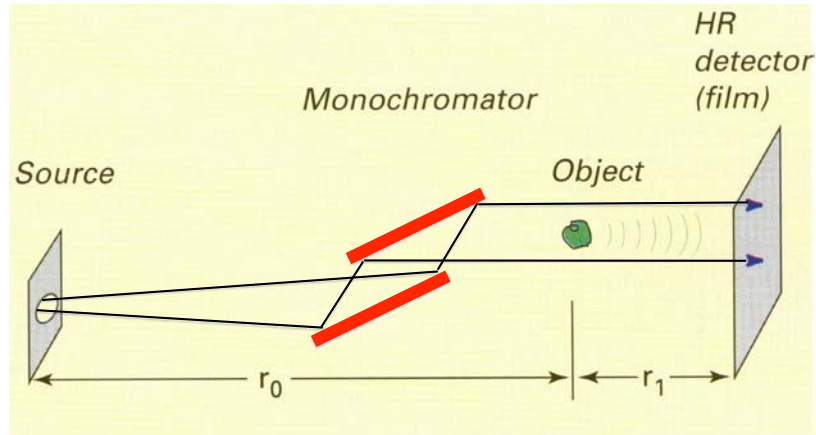


Milestones likely not to be up to date

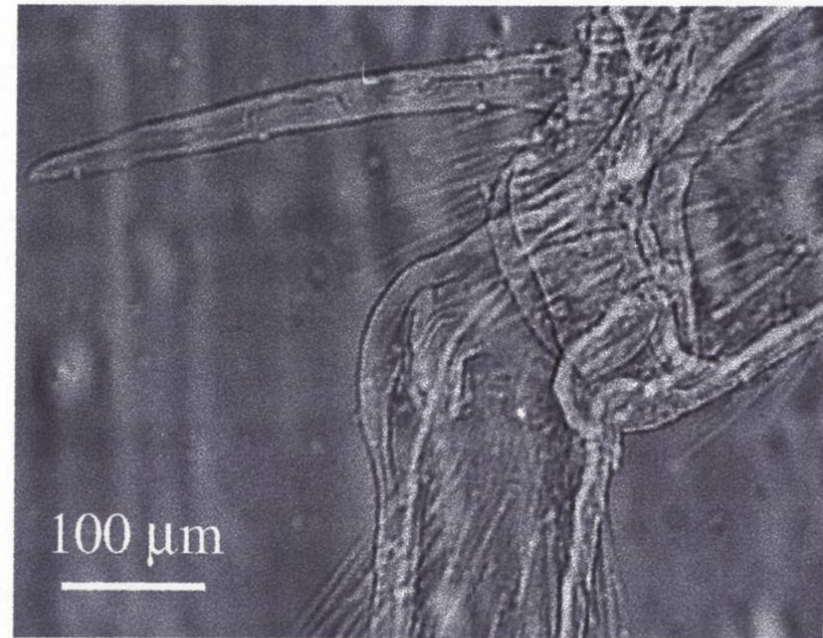
- **Introduction**
 - What are X-rays ?
 - How to generate X-rays ?
 - Modern sources for X-rays
- **Applications in life-science** ←
 - Imaging of organism
 - Structure of biomolecules
 - Function of biomolecules
- **Outlook**
 - Dream of many structural biologist

Imaging of slightly absorbing objects

Phase contrast imaging: $\xi \sim \lambda r_0/s$

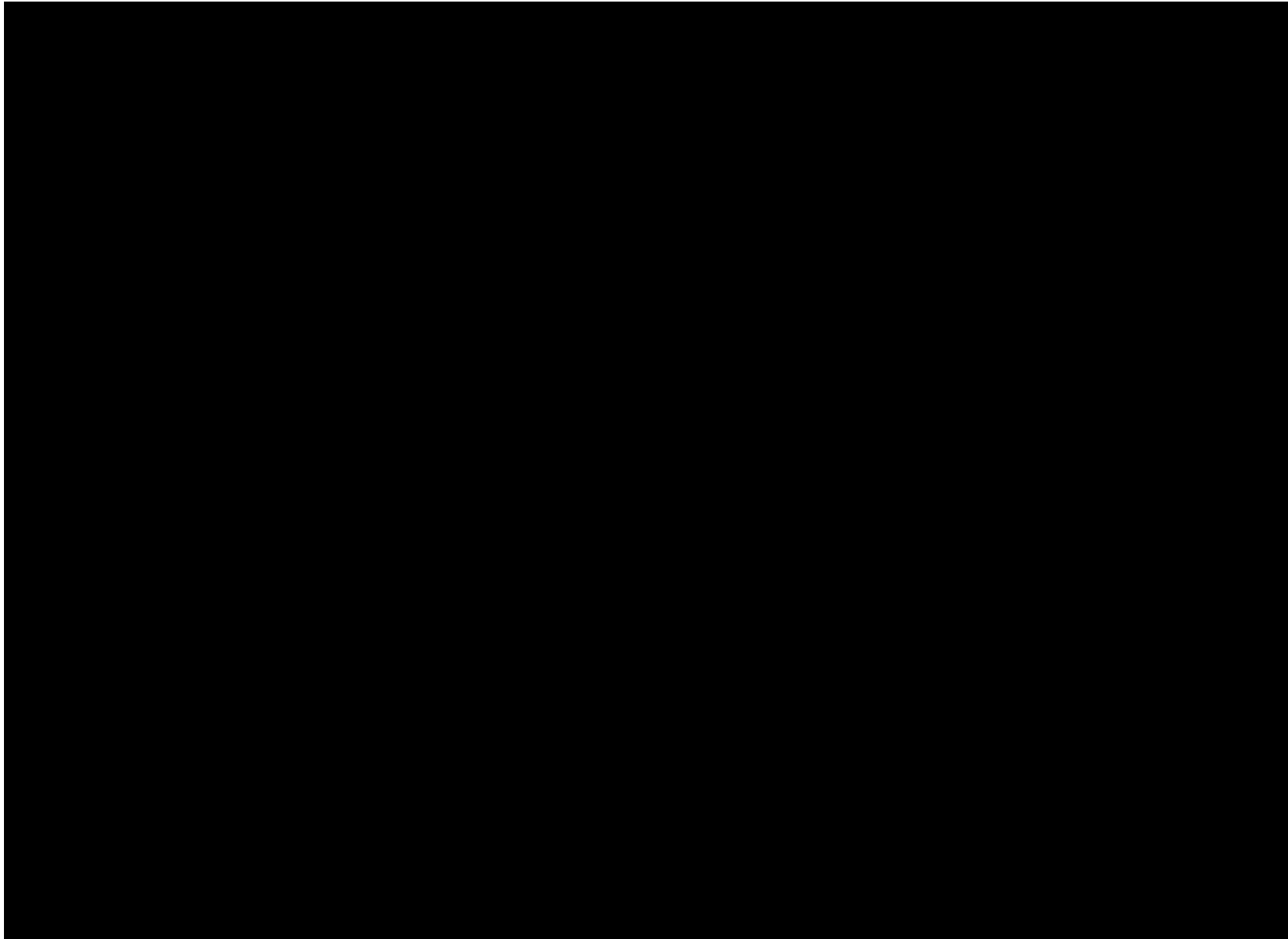


Daddylonglegs knee



Phase contrast image

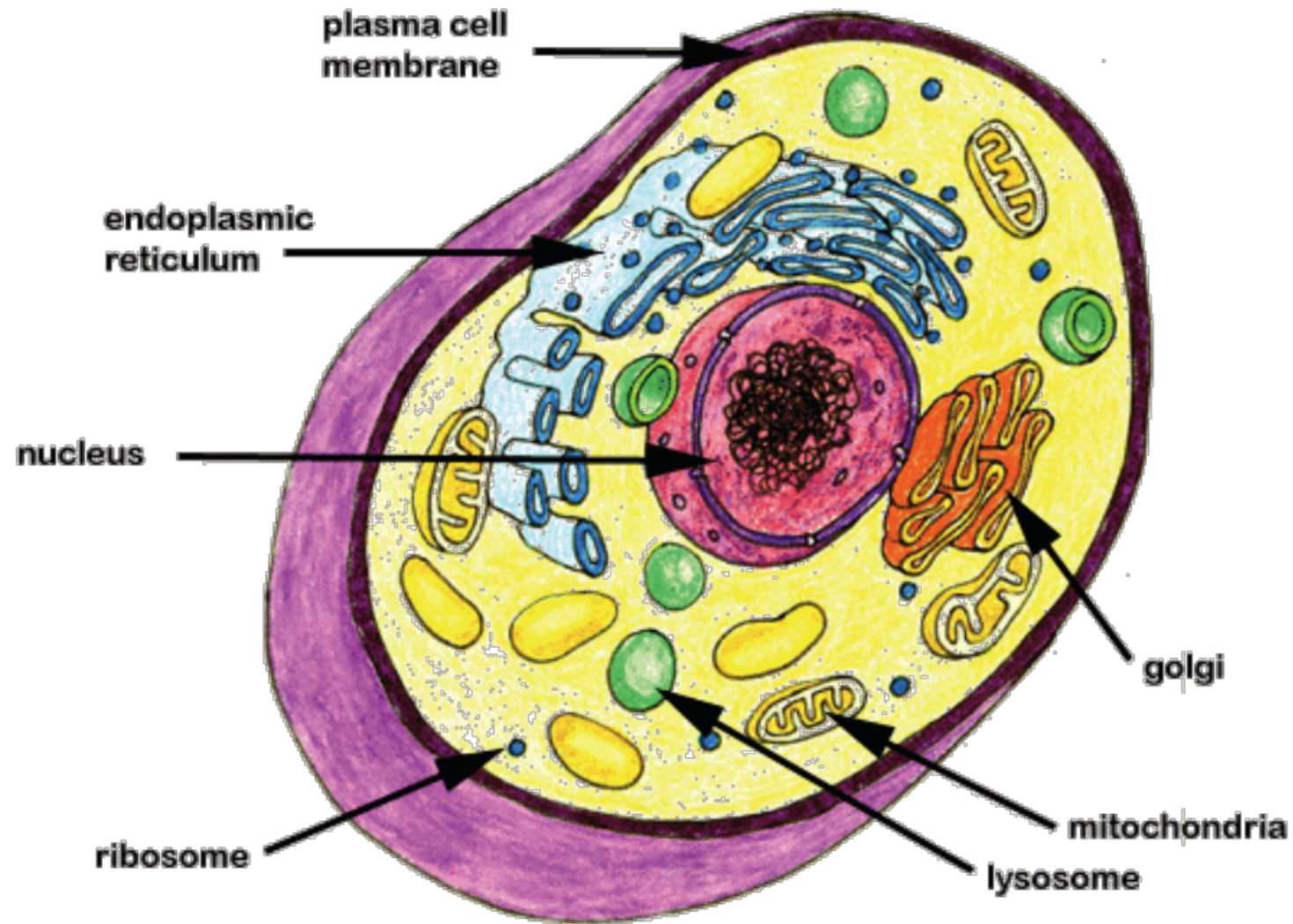
High resolution tomography of rare insects



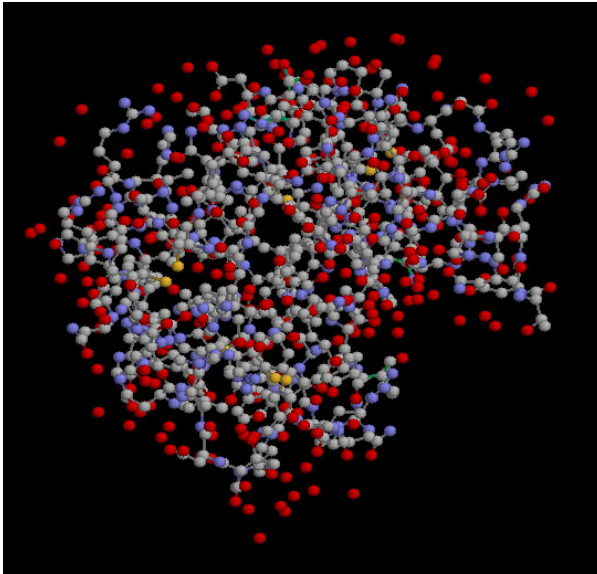
F. Beckmann et al.



How does life work ? Structure of a cell ?

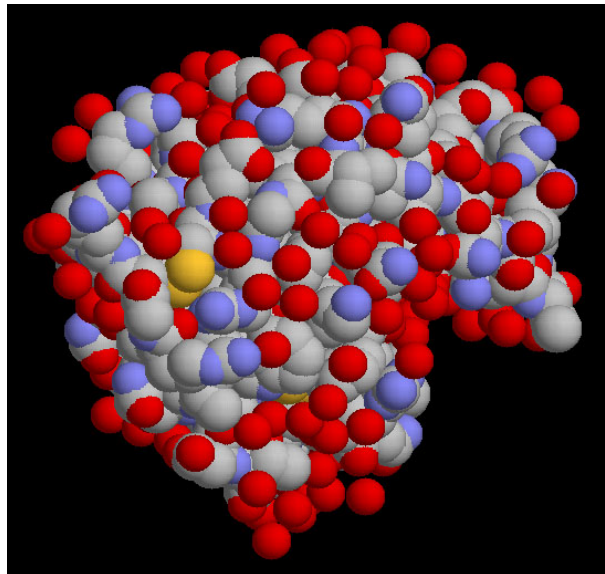


Proteins: lysozyme, different representations



Atoms as small balls

grey: carbon
blue: nitrogen
red: oxygen
yellow: sulfur



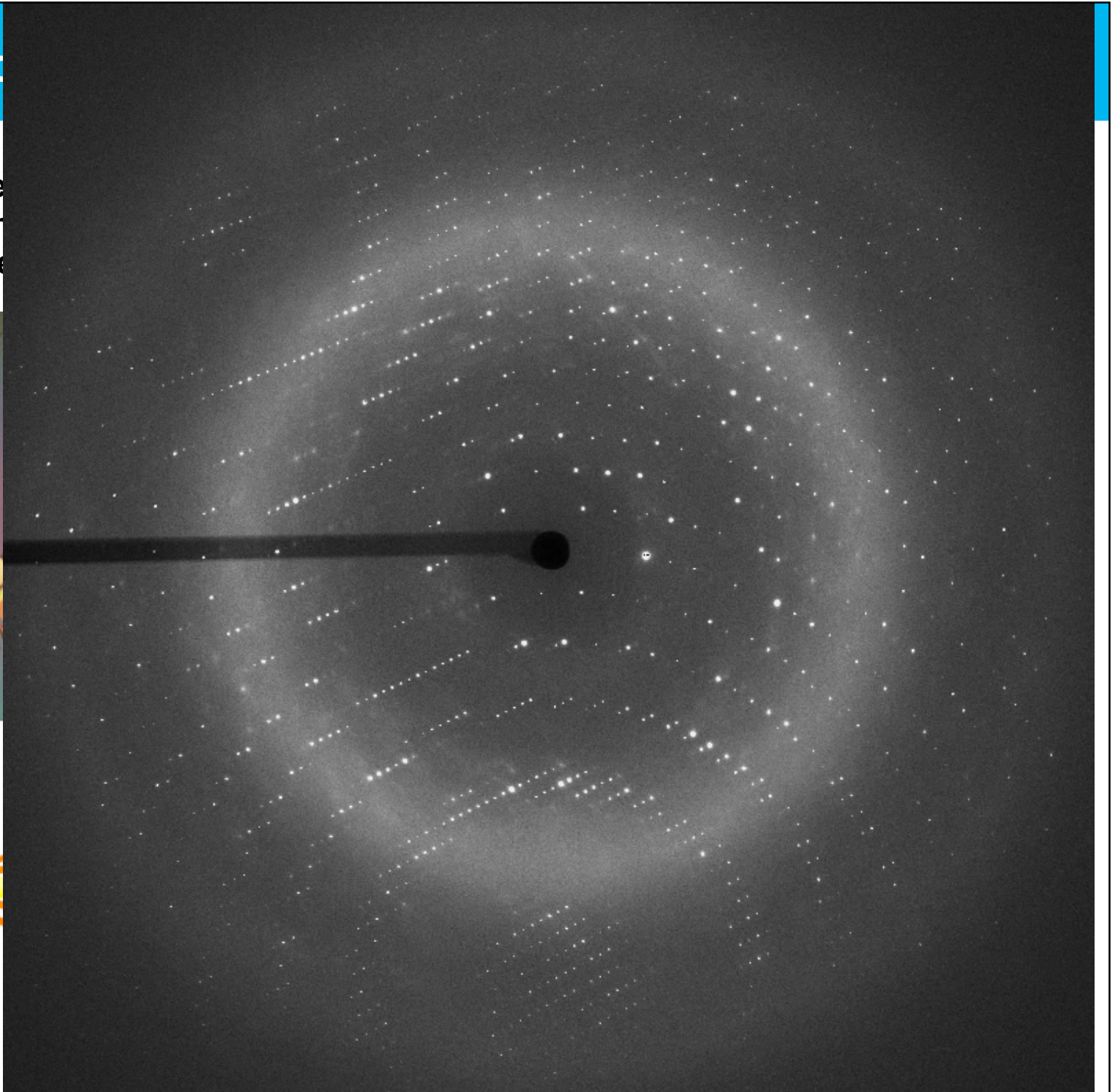
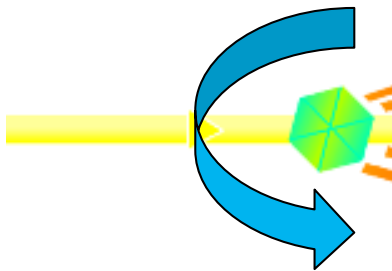
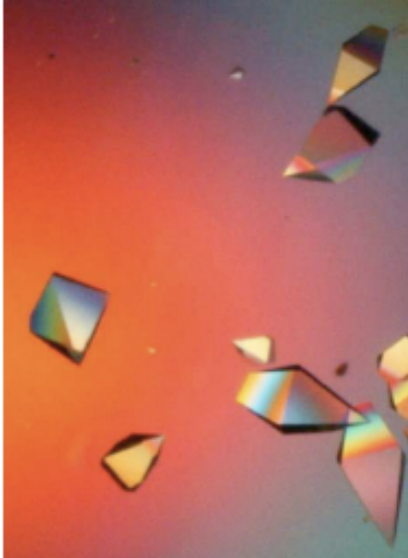
**Atoms as spacefilling
spheres**



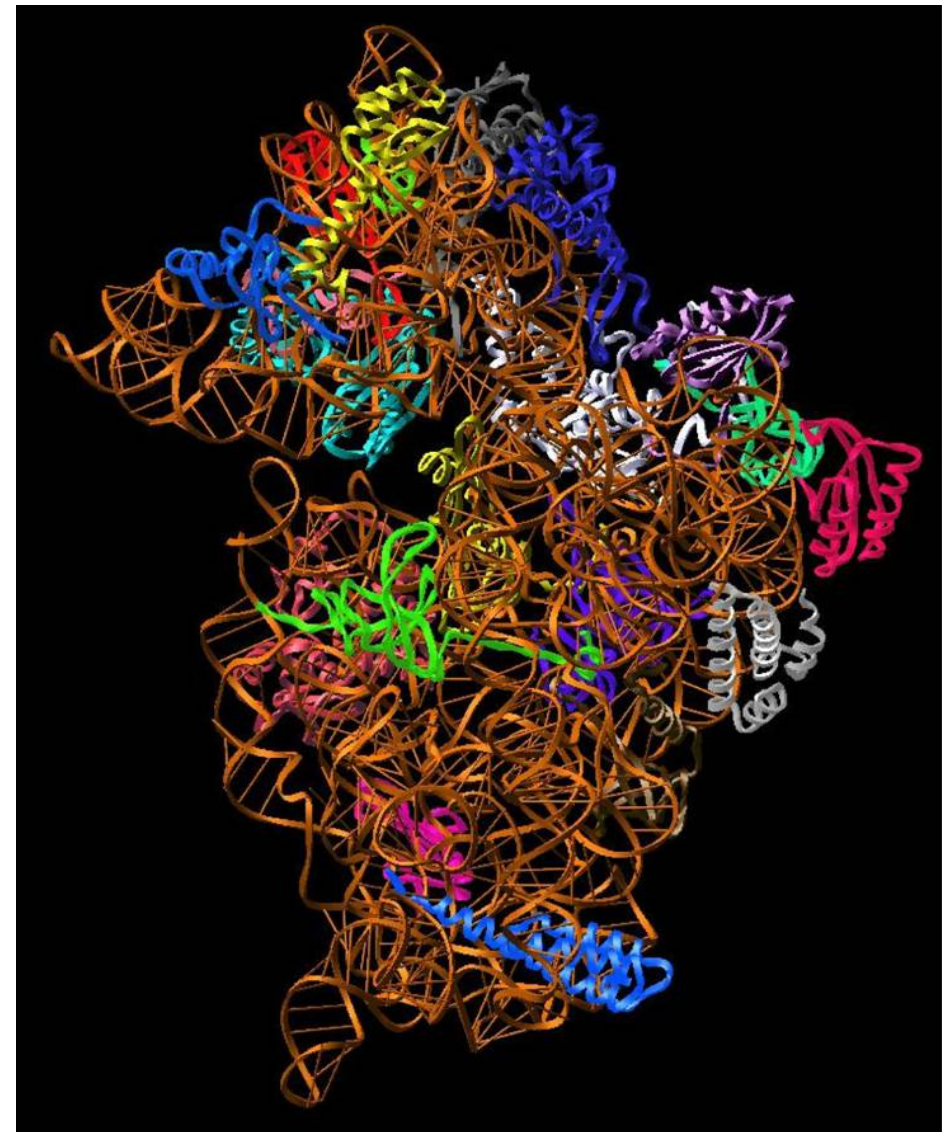
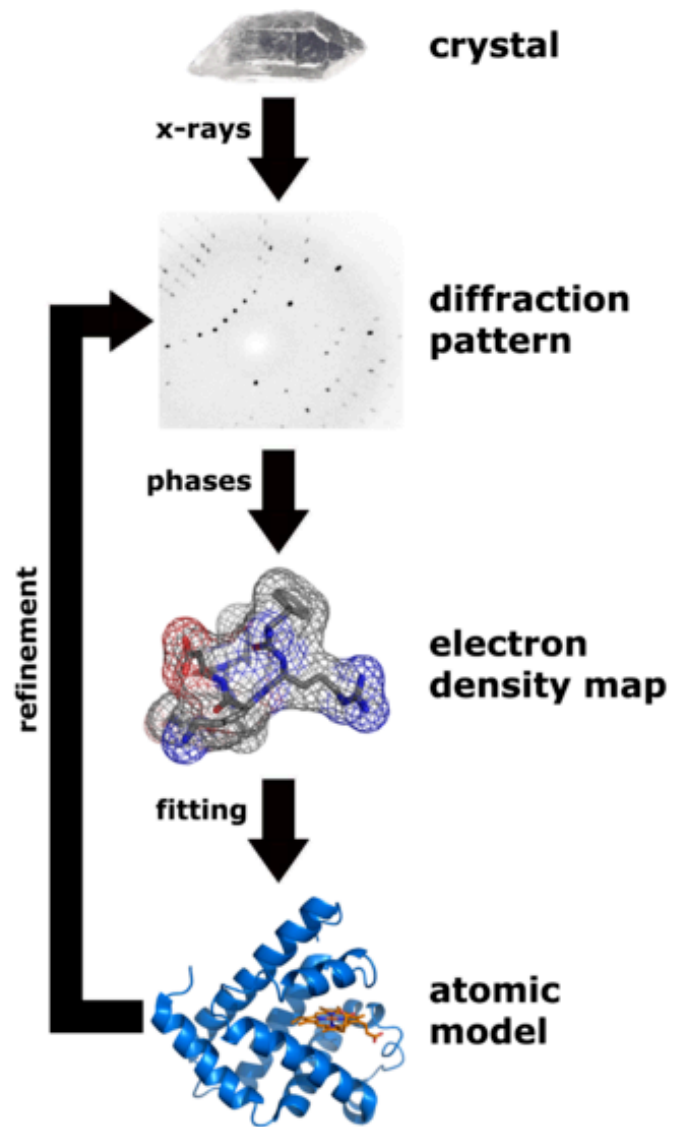
Schematic representation

Protein structure

Basis for any understanding
→ three dimensional
→ crystal structure



Protein structure determination



Ribosome

Examples for recent achievements in structural biology

1. How do muscles work on an atomistic scale

2. How is genetic code translated into proteins



How do muscles work ?

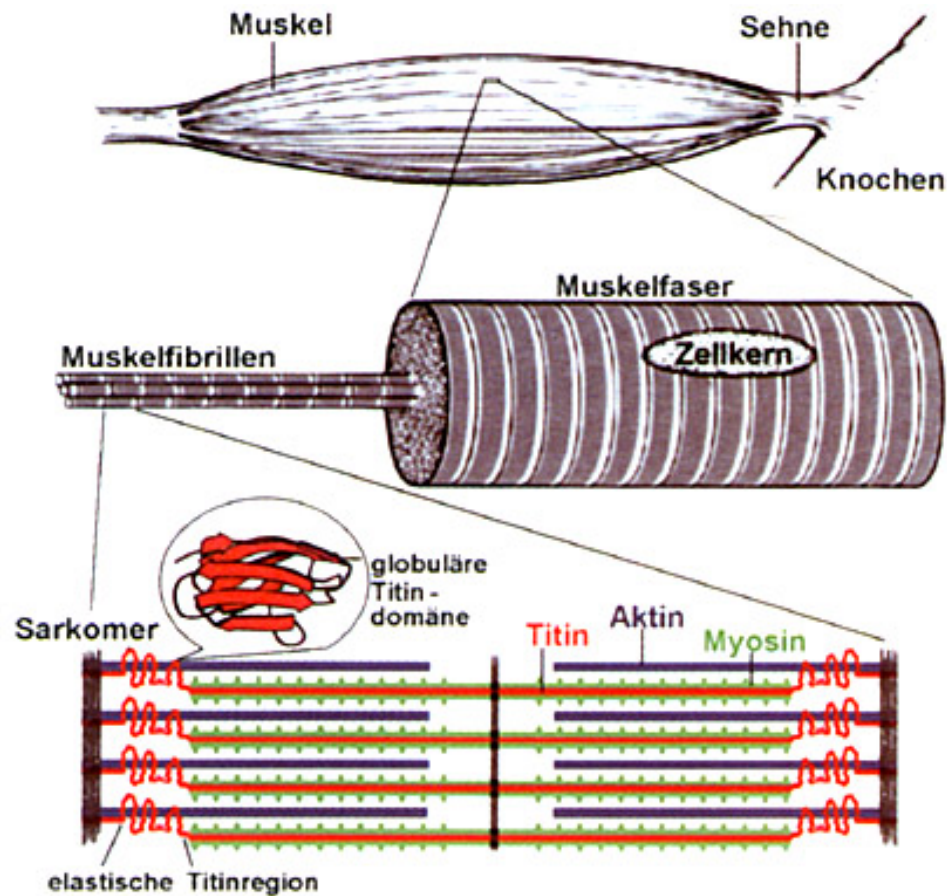
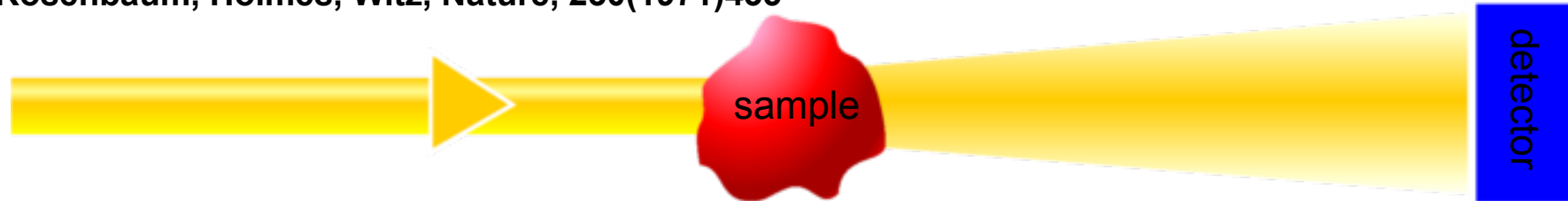


How do muscles work ?

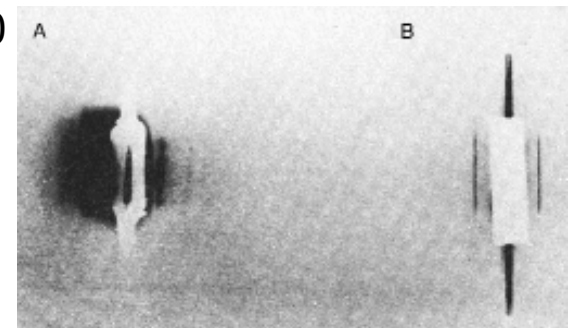


Small angle X-ray scattering from muscle fibres

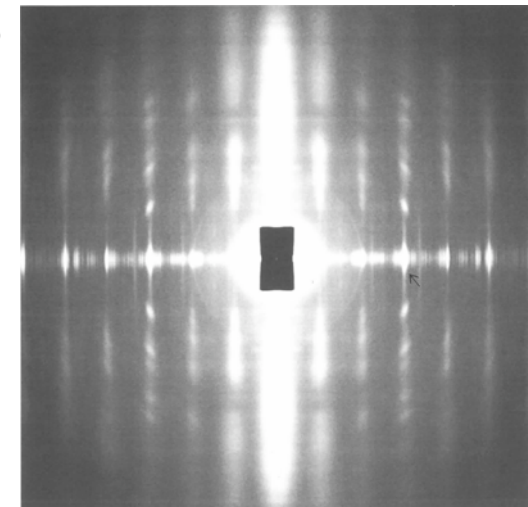
- 1970: first SAXS experiments from biological material
Rosenbaum, Holmes, Witz, Nature, 230(1971)435



1970

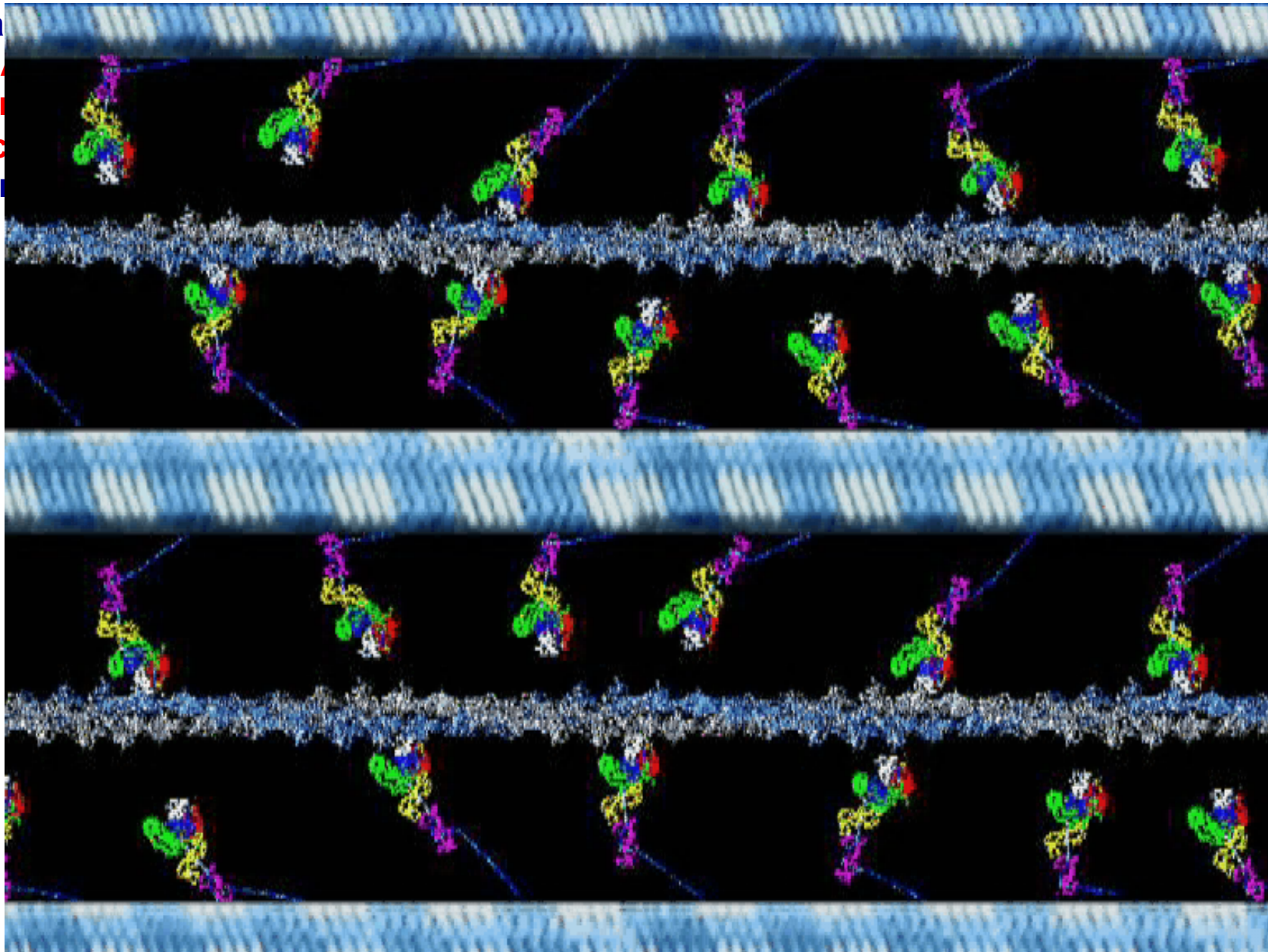


1996

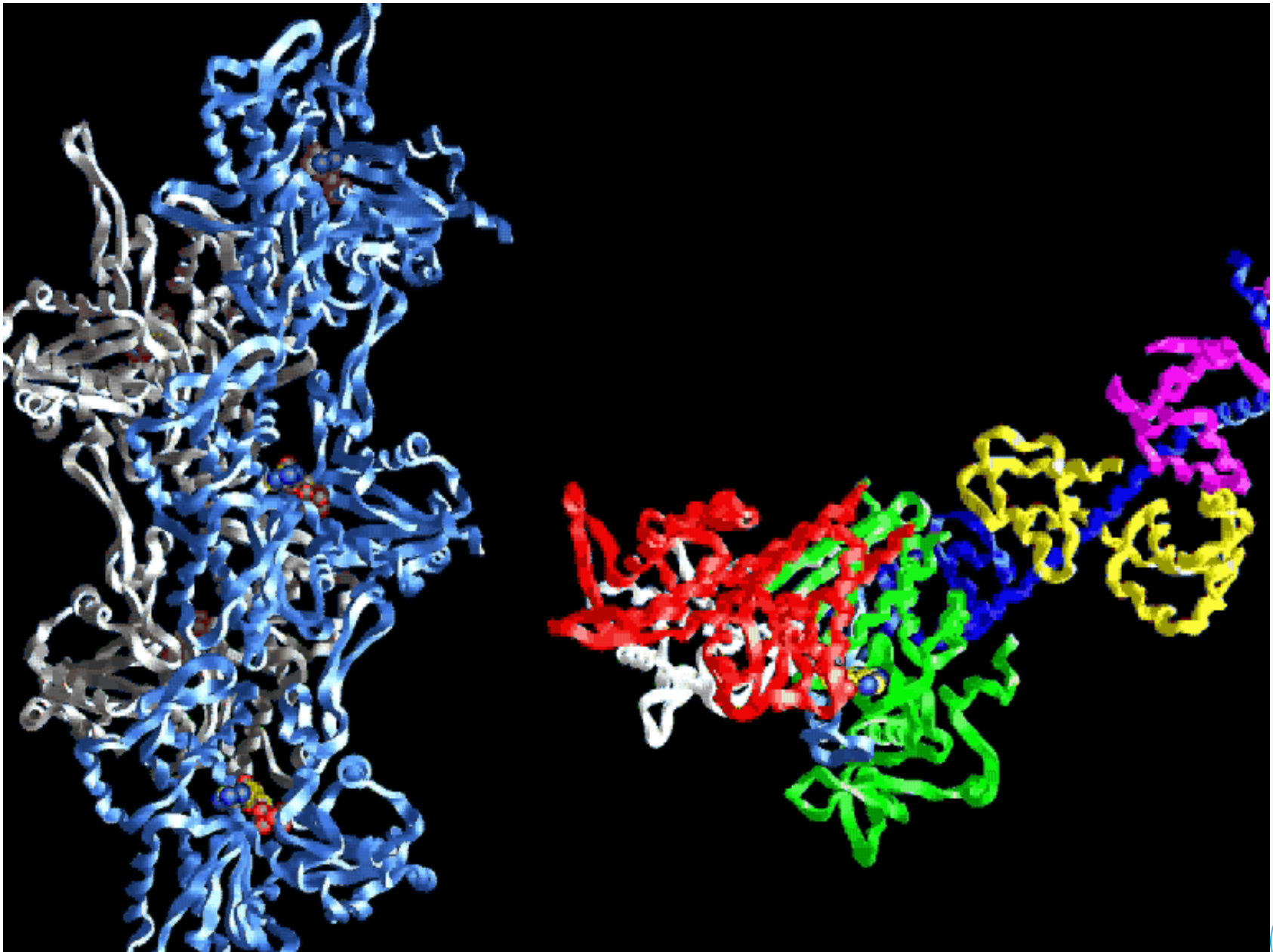


Structure of muscles and how do they work ...

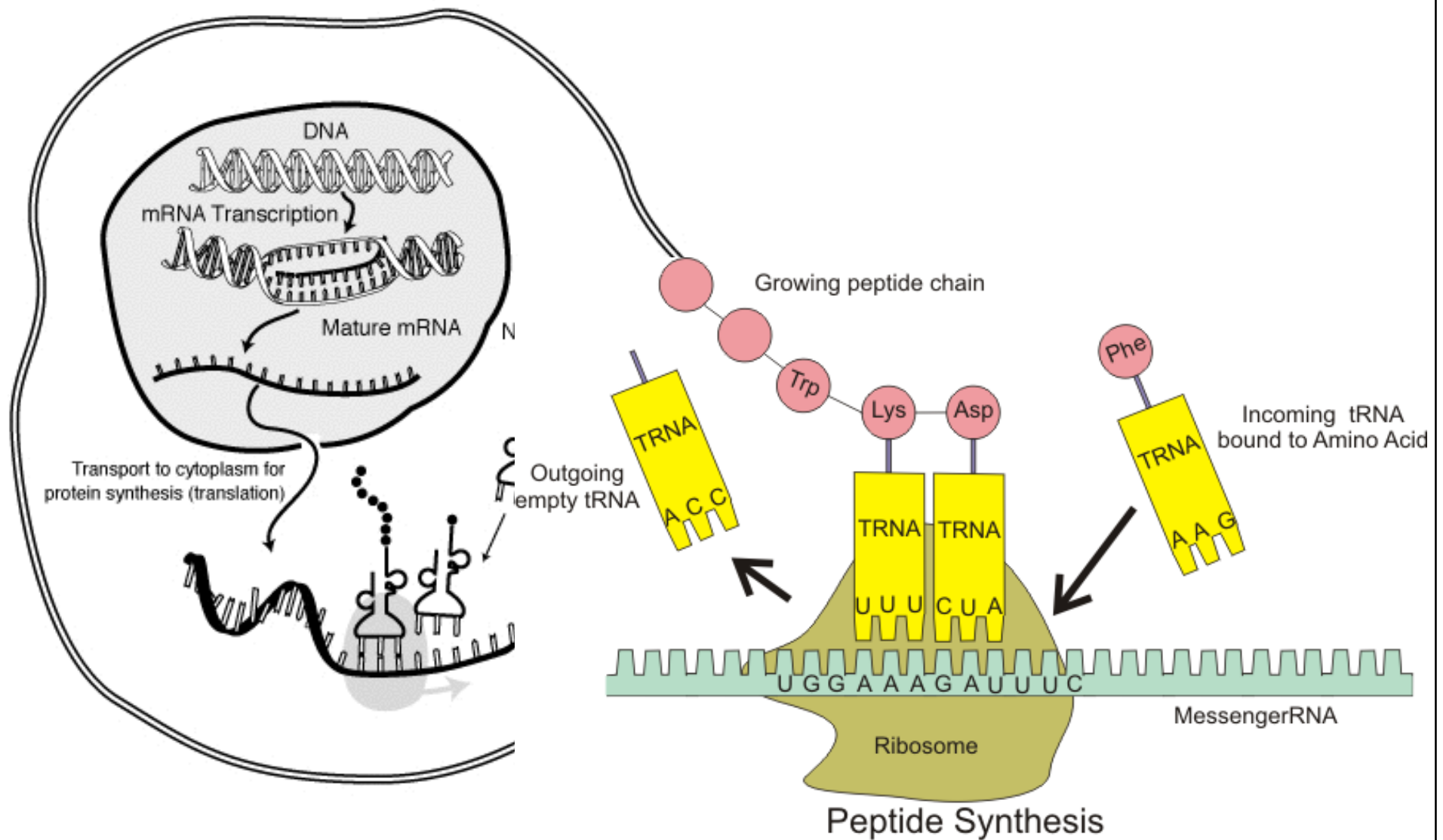
Ma
- S
- p
- (c
un



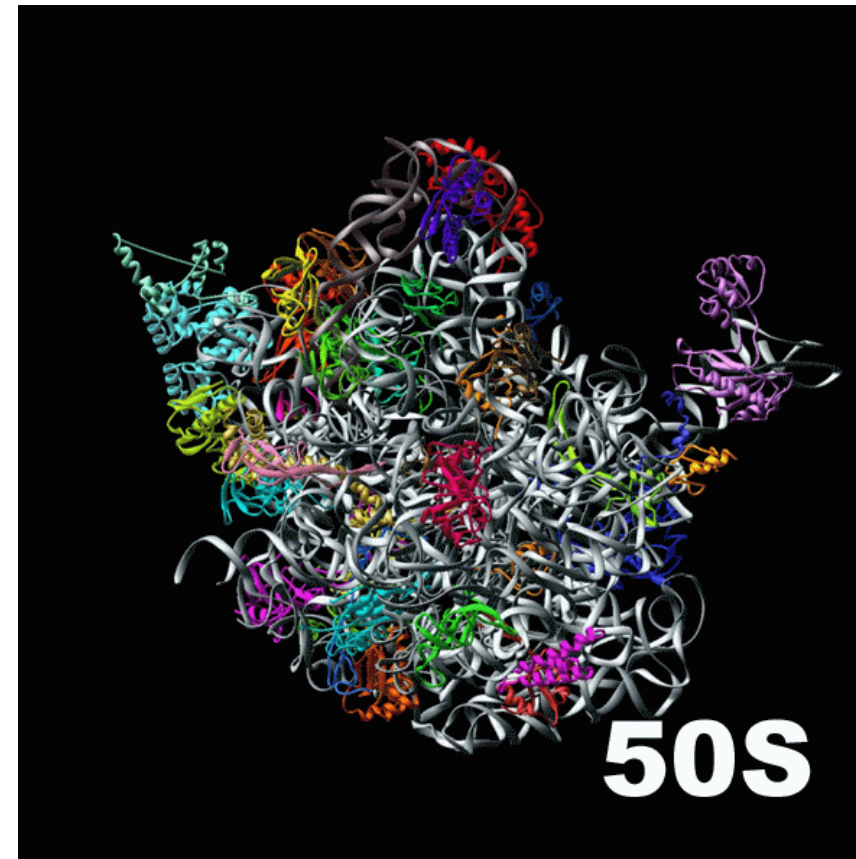
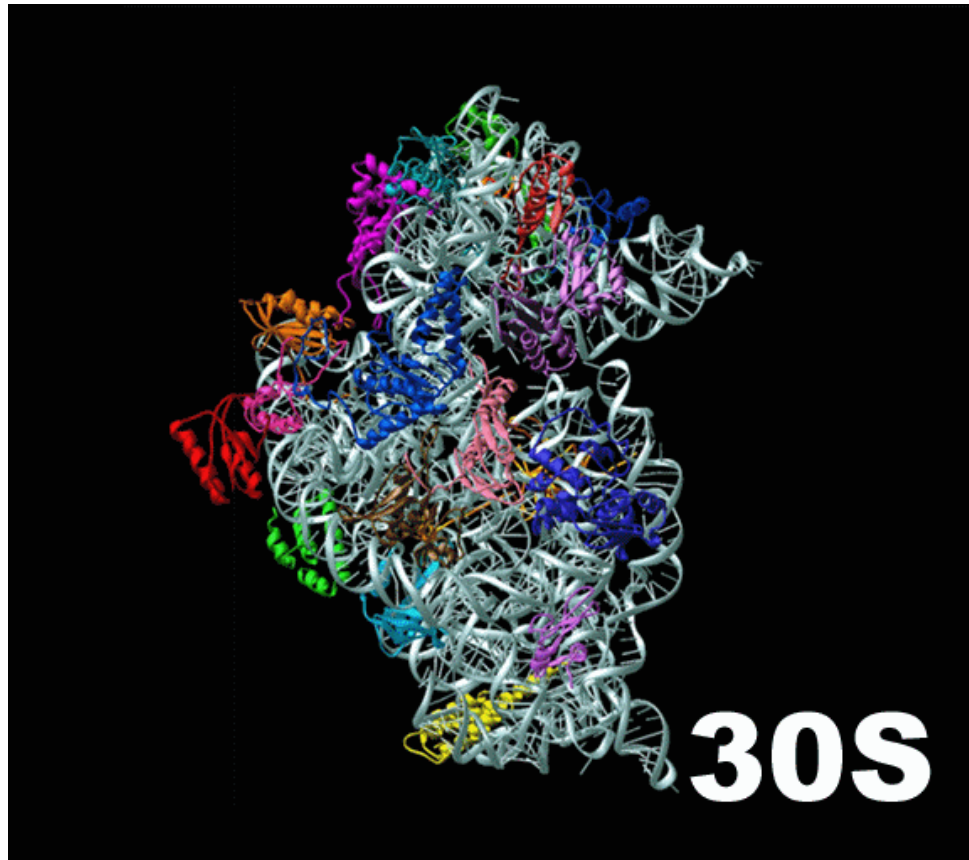
Structure of muscles and how do they work ...



Structure and function of the ribosome ...



Structure and function of the ribosome ...



http://www.weizmann.ac.il/sb/faculty_pages/Yonath/home.html

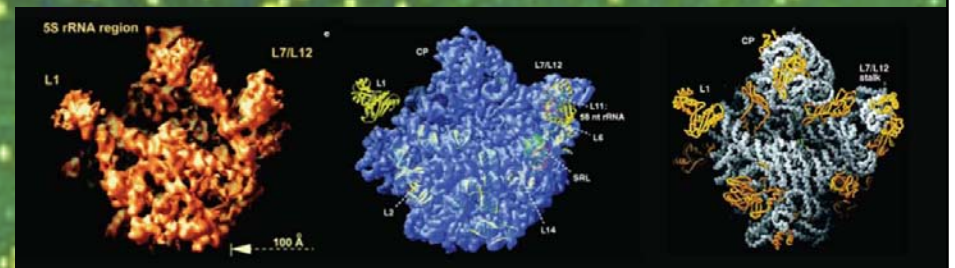
[Schlunzen et al., Cell, 102, 615-23 \(2000\)](#)

[Harms et al., Cell, 107, 679-88 \(2001\)](#)

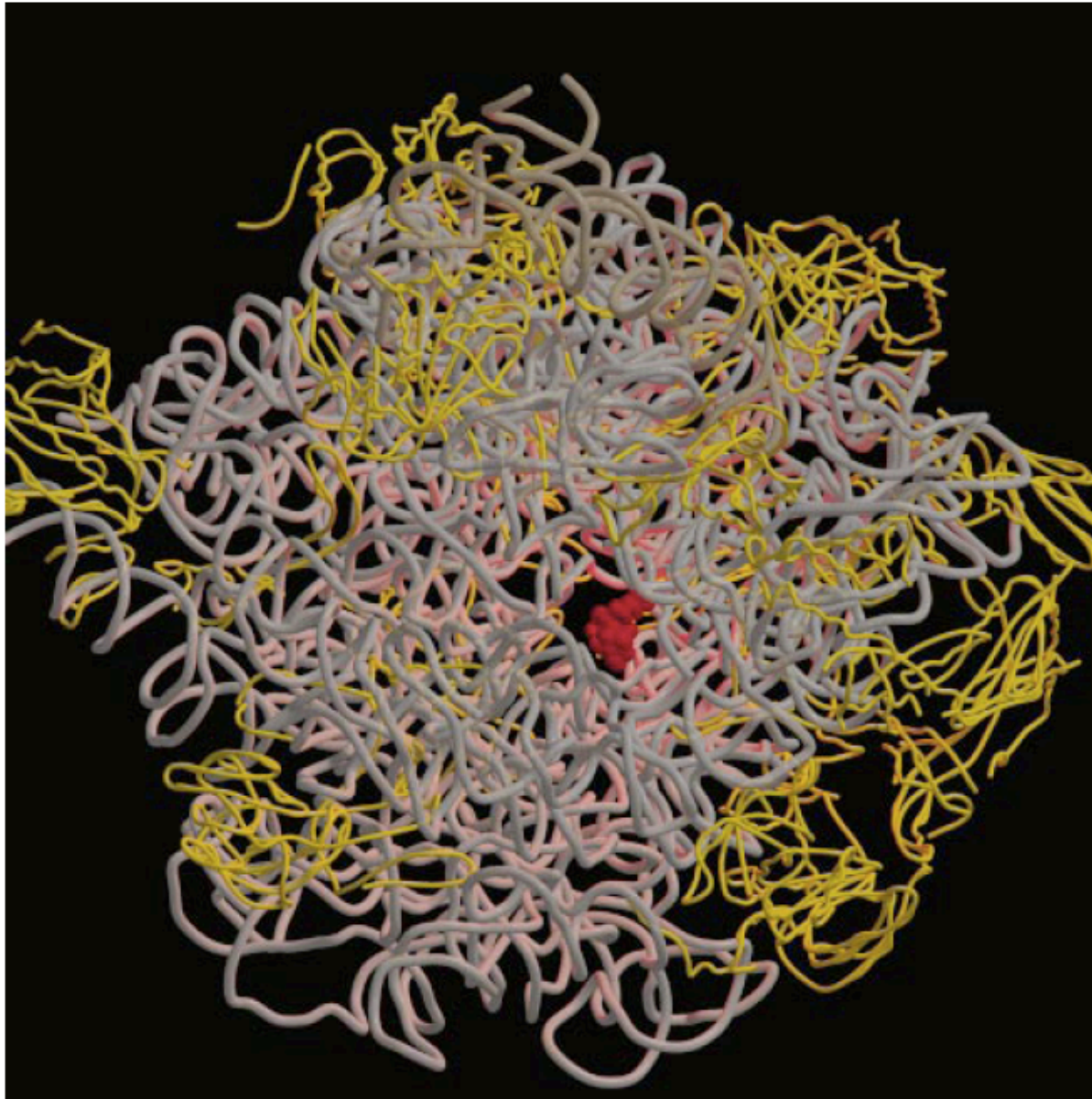


Nobel Price Chemistry 2009.

- > Ada Yonath (together with V. Ramakrishnan und T. Steitz)
- > Pioneered Ribosome crystallography
- > 1986-2004 Head of Max-Planck group „Ribosomstruktur“ at **DESY**
- > Key X-ray experiments at **DORIS / BW6**



Effect of antibiotics on the ribosome



Schlünzen, ..., Yonath, ...
Nature, 413(2001)814



Ribosom *D. radiodurans* 50S
Erythromycin (red)

- **Introduction**
 - What are X-rays ?
 - How to generate X-rays ?
 - Modern sources for X-rays
- **Applications in life-science**
 - Imaging of organism
 - Structure of biomolecules
 - Function of biomolecules
- **Outlook ←**
 - Dream of many structural biologist

Possible applications of X-ray FELs ... dreams we have ...

- 1. Making of 'molecular movies'**
- 2. Diffraction from single particles**



Time resolved diffraction

Example:

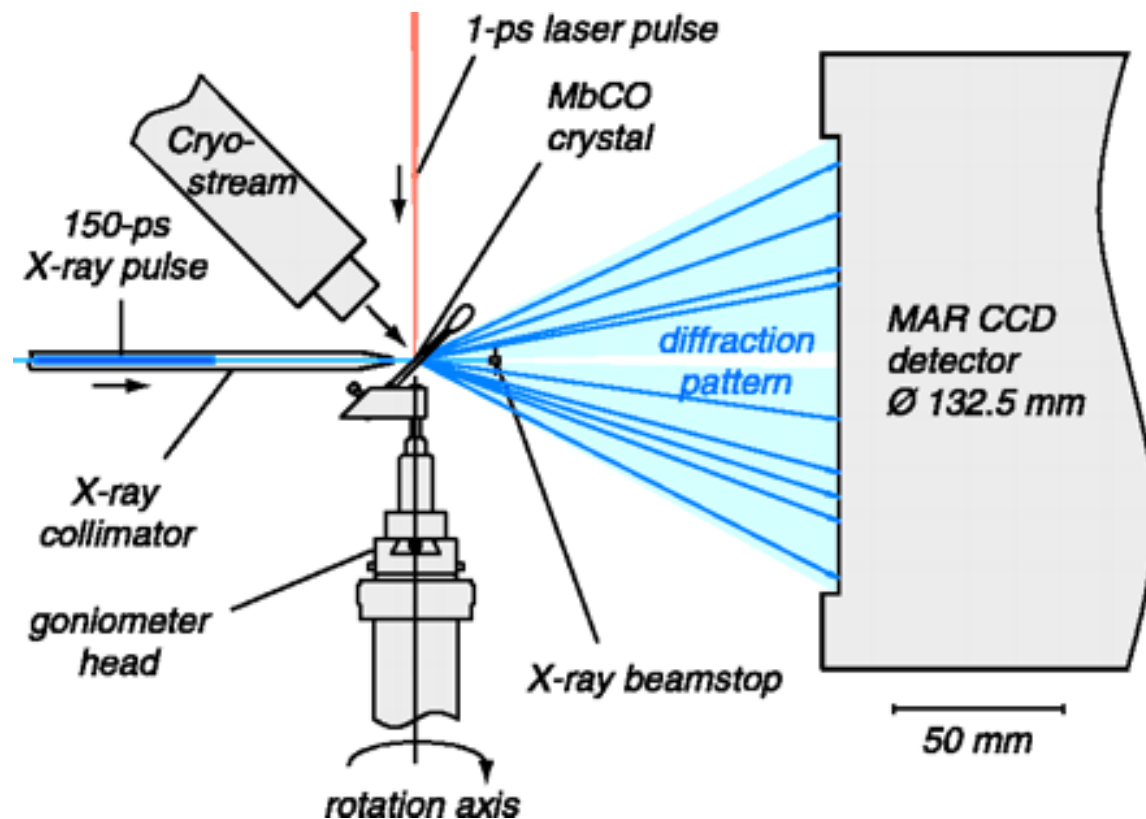
Time resolved investigation of the photo ionization of CO-myoglobin at ID9 (ESRF):

- pump-probe technique
- X-ray crystallography

Variable delay between
laser pump pulse and
X-ray probe pulse.

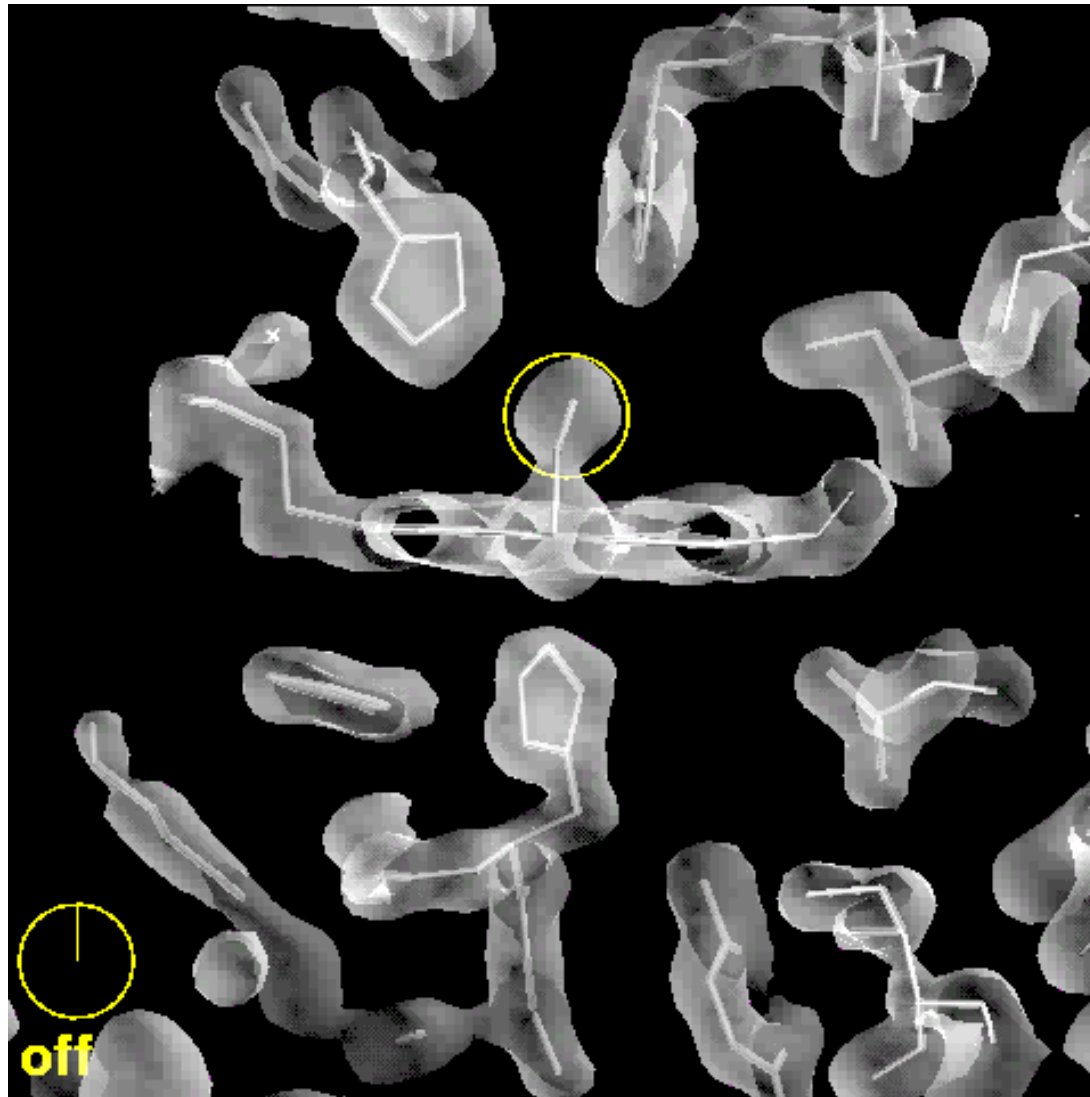
32 exposures per
image

‘pink’ Laue technique,
range: 0.72-1.24 Å



Schotte et al., Science 300(2003)1944

Time resolved crystallography



XFEL: 1000-10000 times better time resolution than today

Schotte et al., Science 300(2003)1944

Conclusion

- **Modern X-ray sources are providing photon beams of unprecedented properties**
- **A number of new sources are under construction or being commissioned**
- **Storage ring based X-ray sources did and will contribute significantly to the solution of structural problems in life sciences**
- **New FEL source will enable totally new insight in structural biology problems:**
 - **watching molecules in action**
 - **study of systems far away from equilibrium**
 - **single particle imaging**





The image is an aerial photograph of the DESY campus, which is a large scientific facility. The campus is surrounded by greenery and trees. Several buildings and areas are highlighted with orange labels and arrows. The labels include: 'ZOO' (pointing to a building on the left), 'PETRA III (east)' (pointing to a building in the upper left), 'EMBL@PETRA III' (pointing to a building in the upper left), 'office and laboratories' (pointing to a building in the upper center), 'European XFEL' (pointing to a building on the right with a large arrow), 'CFEL' (pointing to a building in the lower left), 'DORIS III' (pointing to a building in the center), 'MAMO LAB' (pointing to a building in the center), 'CSSB' (pointing to a building in the center), 'office and laboratories' (pointing to a building in the center), 'PETRA III' (pointing to a large circular building in the center), 'FLASH II' (pointing to a building in the lower left), 'FLASH' (pointing to a building in the lower left), 'PETRA III (north)' (pointing to a building in the lower center), 'GKSS EMSC' (pointing to a building in the lower center), and 'AMTF' (pointing to a large building on the right). The text 'Thank you for your attention' is overlaid in the center of the image in a large, bold, blue font.

Thank you for your attention