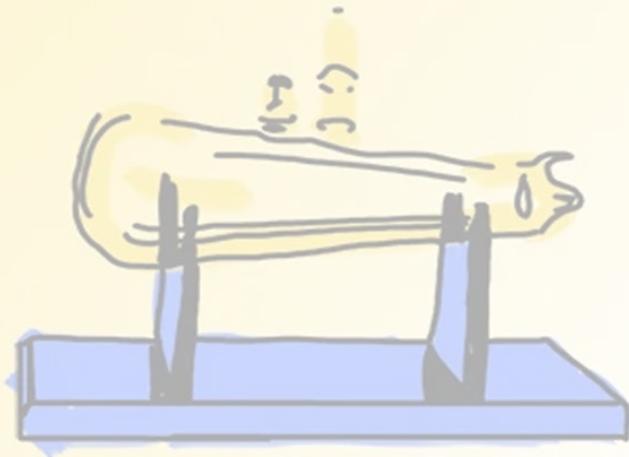


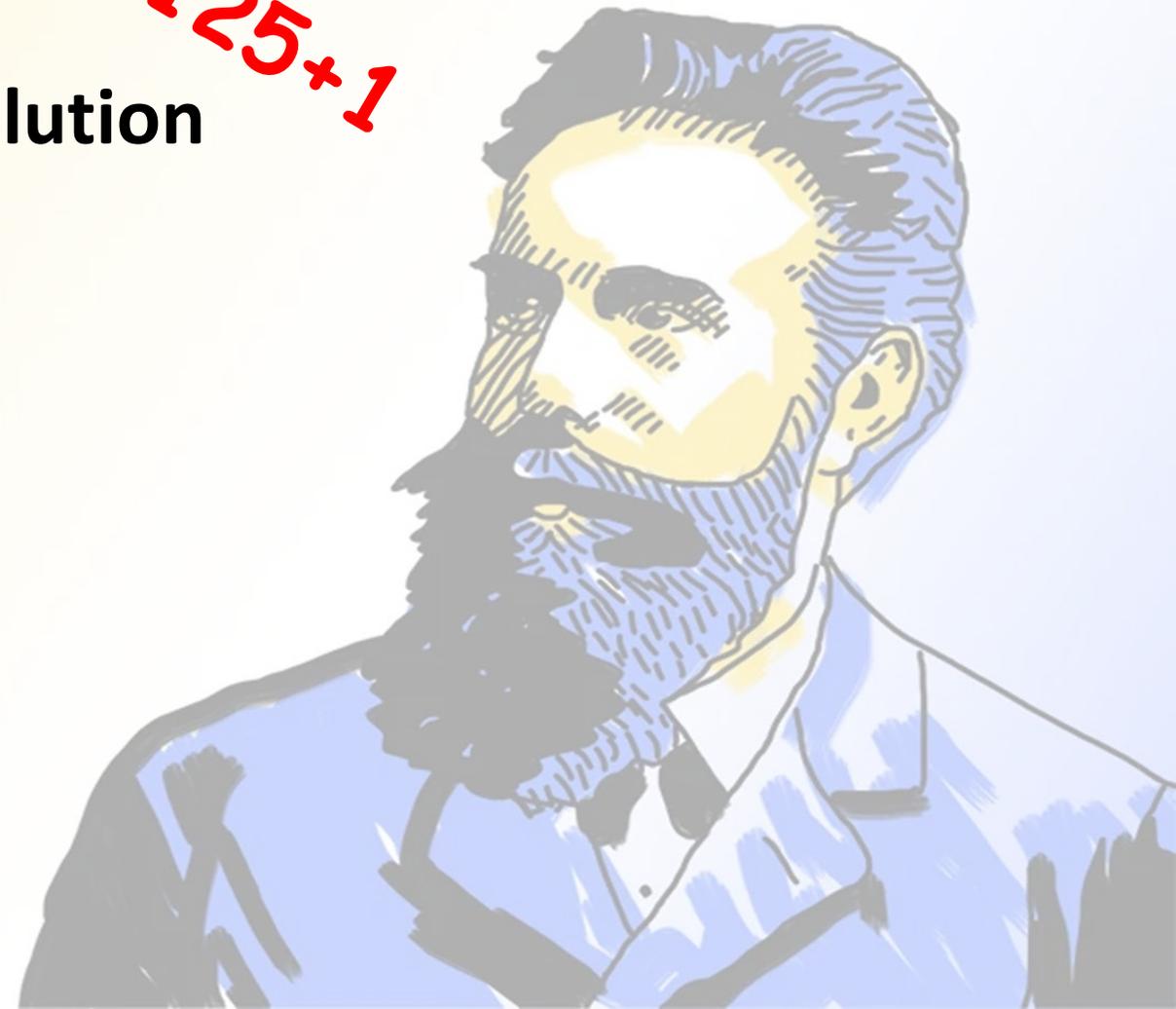
# Röntgen's Discovery – From Serendipity to Scientific Revolution

125+1



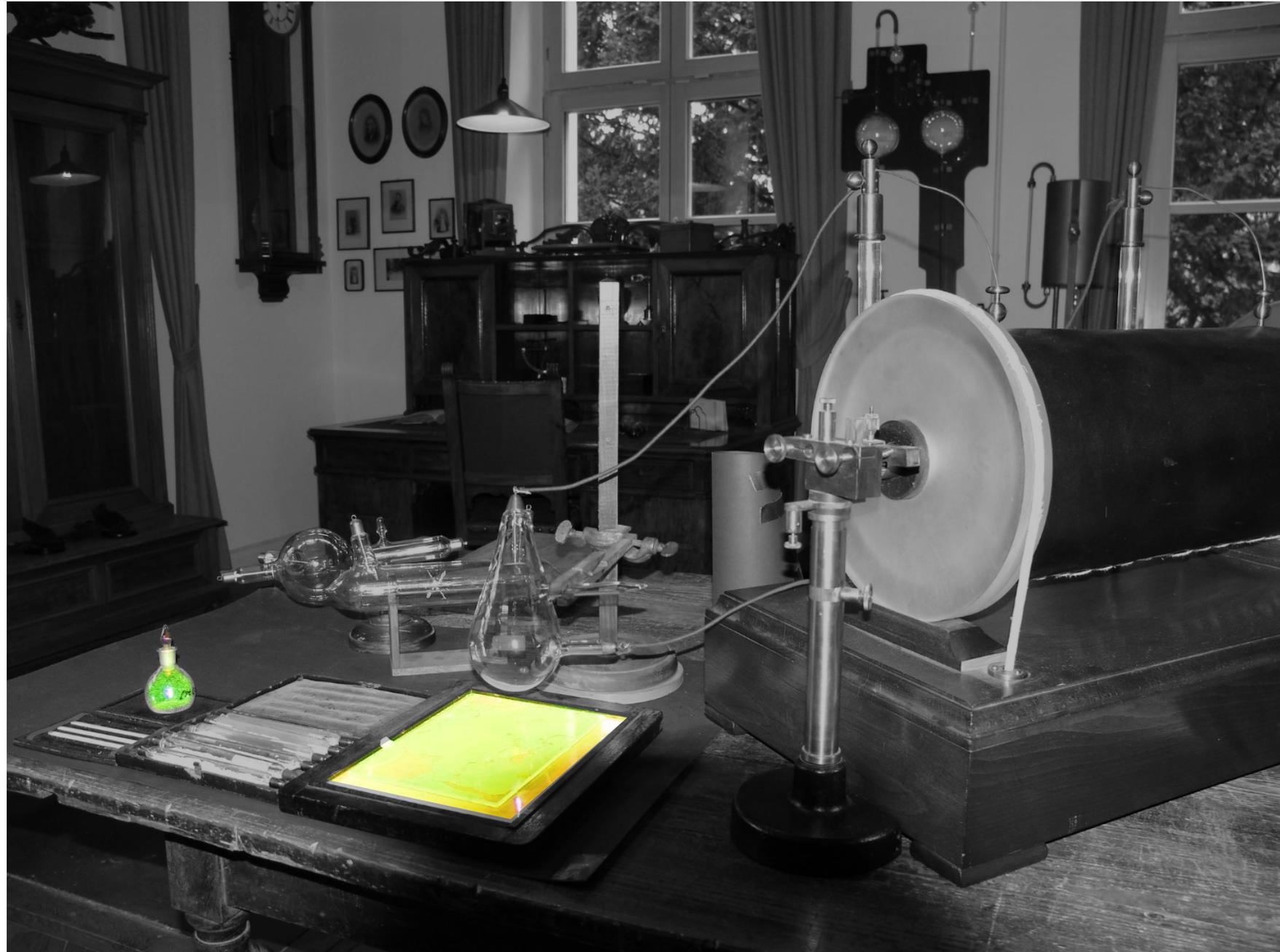
**Ralph Claessen**

Physikalisches Institut &  
Würzburg-Dresden Cluster of Excellence "ct.qmat"  
Julius-Maximilians-Universität Würzburg  
Germany



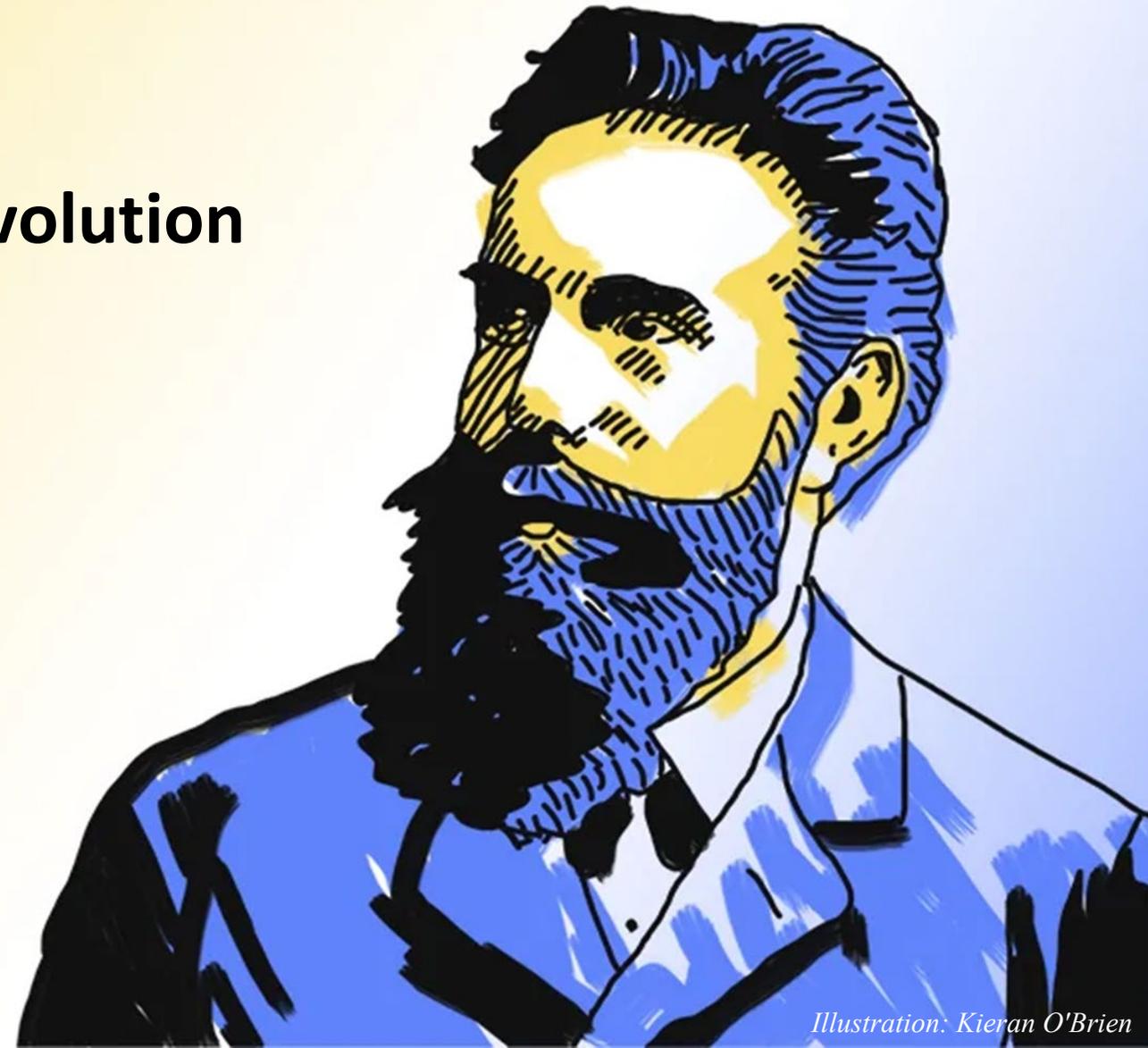
**November 8, 1895: a Friday evening in the lab...**

...at the Physikal. Institut,  
Universität Würzburg



# Röntgen's Discovery – From Serendipity to Scientific Revolution

- Biographical Notes
- The Discovery of the X-Rays
- Scientific Impact and Beyond



# Biographical Notes



**27 March 1845**

Wilhelm Conrad Röntgen is born in Lennep  
(Remscheid, Bergisches Land)

175+1

**1848**

Röntgen's family moves to Apeldoorn (NL)

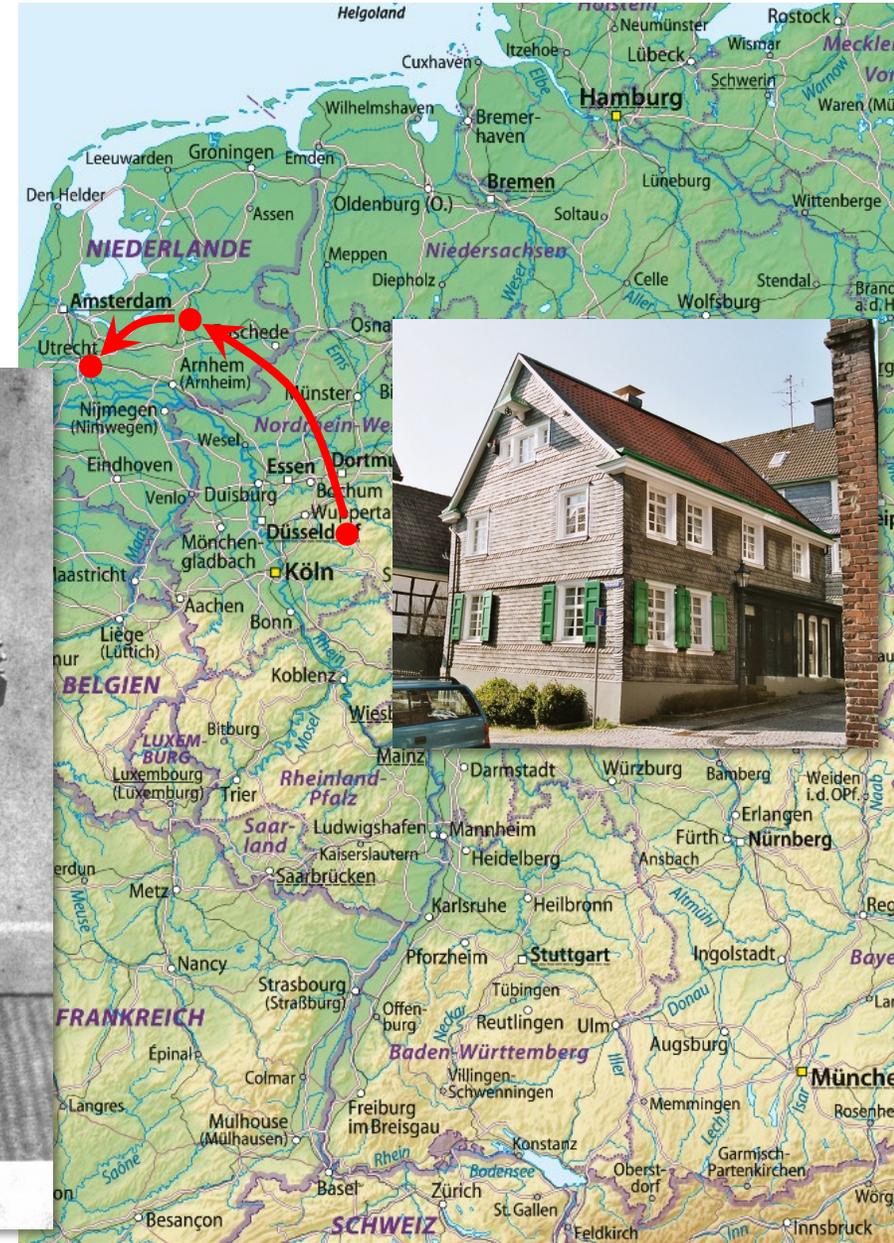
**1861**

Röntgen attends "Utrecht Technical School"

**1863/64**

Röntgen gets unfairly discharged from school  
without a high school diploma ("*Abitur*")

He nonetheless starts attending lectures in  
chemistry, physics, zoology and botanics at  
U Utrecht



1865 - 1868

student of mechanical engineering at *Eidgenössisches Polytechnikum* in **Zürich** (Clausius & Kundt among his teachers)



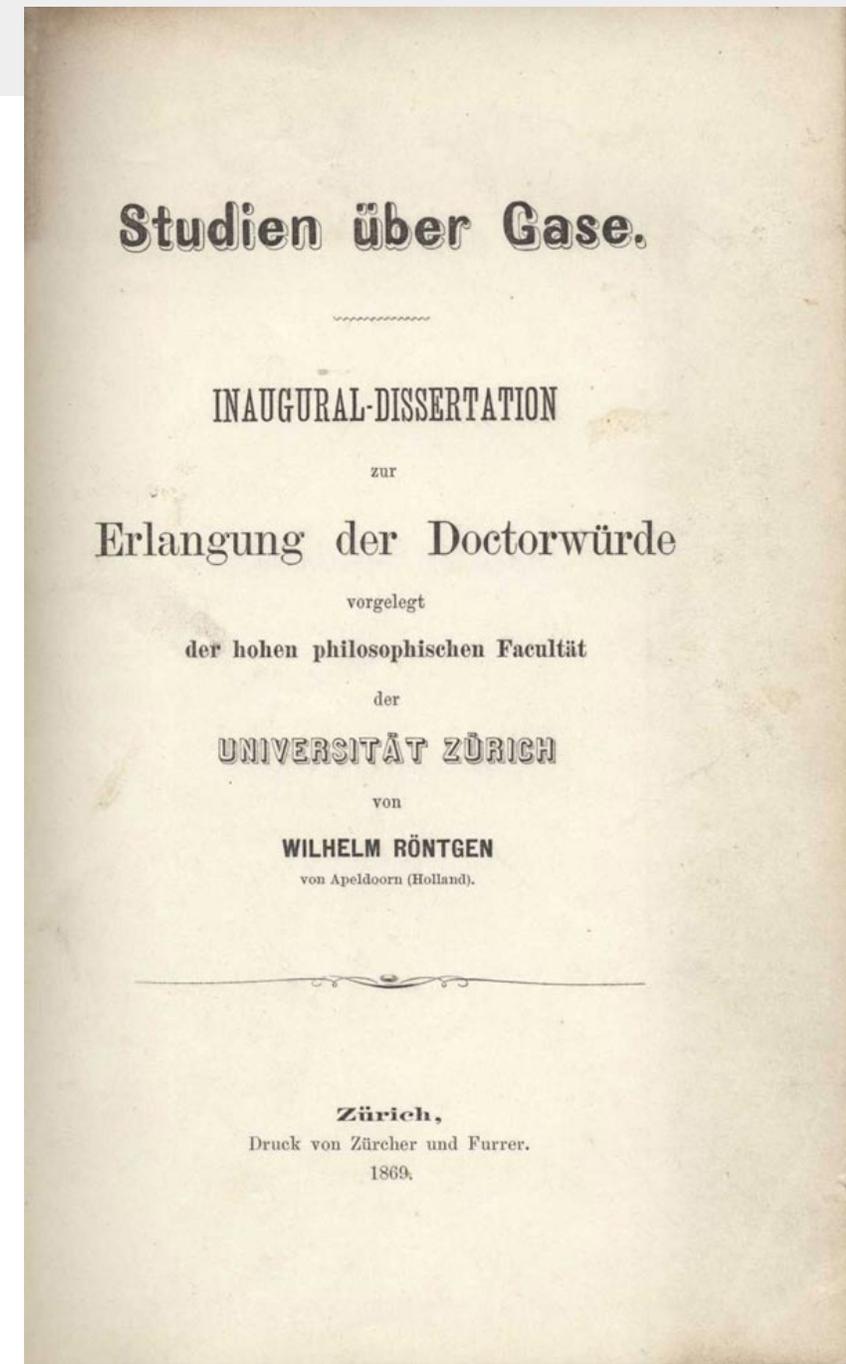


**1865 - 1868**

student of mechanical engineering at *Eidgenössisches Polytechnikum* in **Zürich** (Clausius & Kundt among his teachers)

**1869**

*Dr. Phil.* at U Zürich on "*Studien über Gase*"



**1865 - 1868**

student of mechanical engineering at *Eidgenössisches Polytechnikum* in **Zürich** (Clausius & Kundt among his teachers)

**1869**

*Dr. Phil.* at U Zürich on "*Studien über Gase*"

**1870**

Röntgen moves to **Würzburg** as Kundt's *Assistent*, however, habilitation is denied due to lack of *Abitur*

**1872 - 1874**

Relocation with Kundt to the new *Reichsuniversität Straßburg*, finally: habilitation in Straßburg



**1865 - 1868**

student of mechanical engineering at *Eidgenössisches Polytechnikum* in **Zürich** (Clausius & Kundt among his teachers)

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Relocation with Kundt to the new *Reichsuniversität Straßburg*, finally: habilitation in Straßburg

**1872**

Röntgen marries Anna Bertha Ludwig who he had met in Zürich



# Restaurant zum Grünen Glas

JOBBS



Untere Zäune 15  
8001 Zürich  
+41 44 251 65 04  
[info@gruenesglas.ch](mailto:info@gruenesglas.ch)



Home

1875

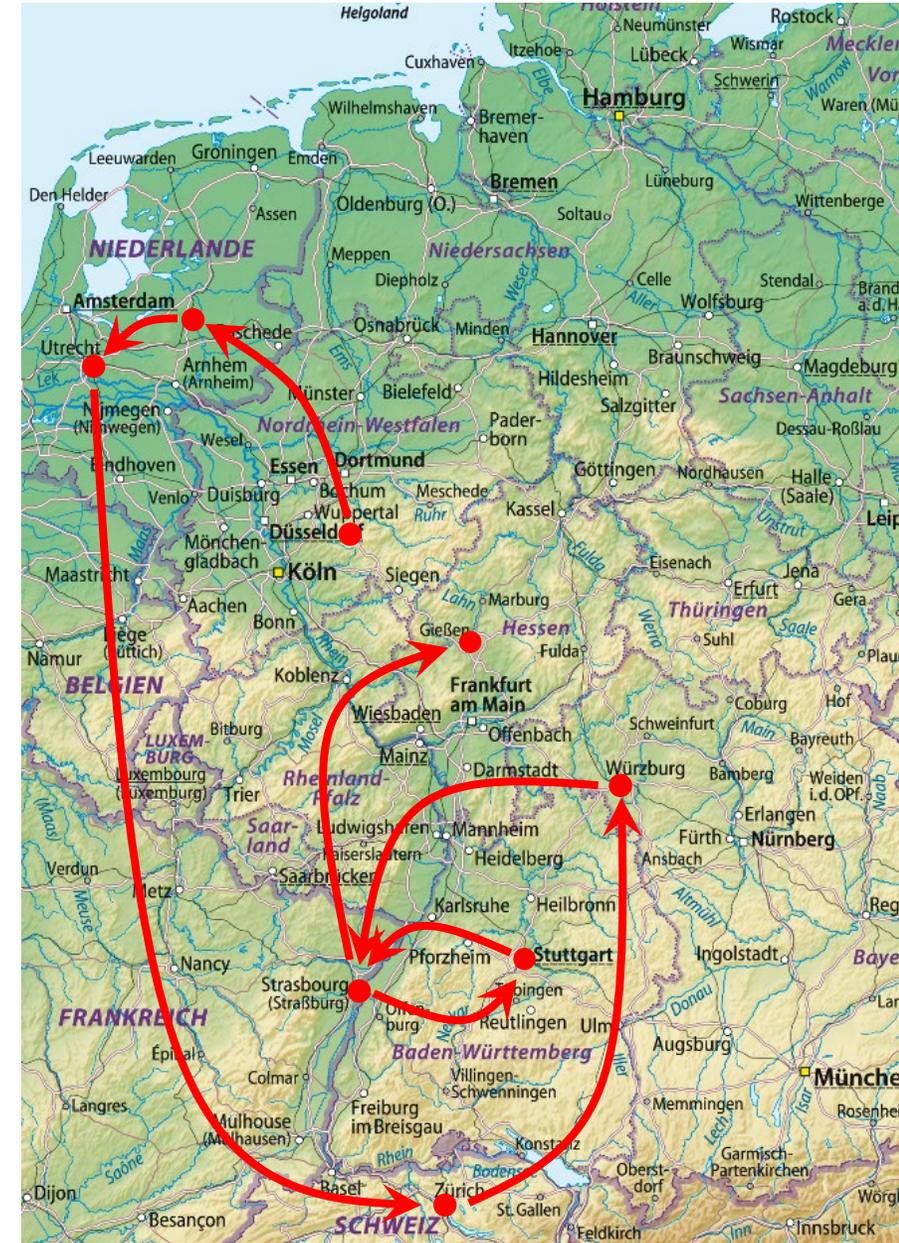
"Extraordinarius" (Assoc. Prof.) at the *Landwirtschaftliche Akademie Hohenheim*

1876

Return to **Straßburg** as "Extraordinarius" for Mathematical Physics

1879

Full Professorship at U **Gießen**



**1888**

Acceptance of full professorship at the newly erected *Physikalisches Institut* in **Würzburg** as successor of Friedrich Kohlrausch

**1894**

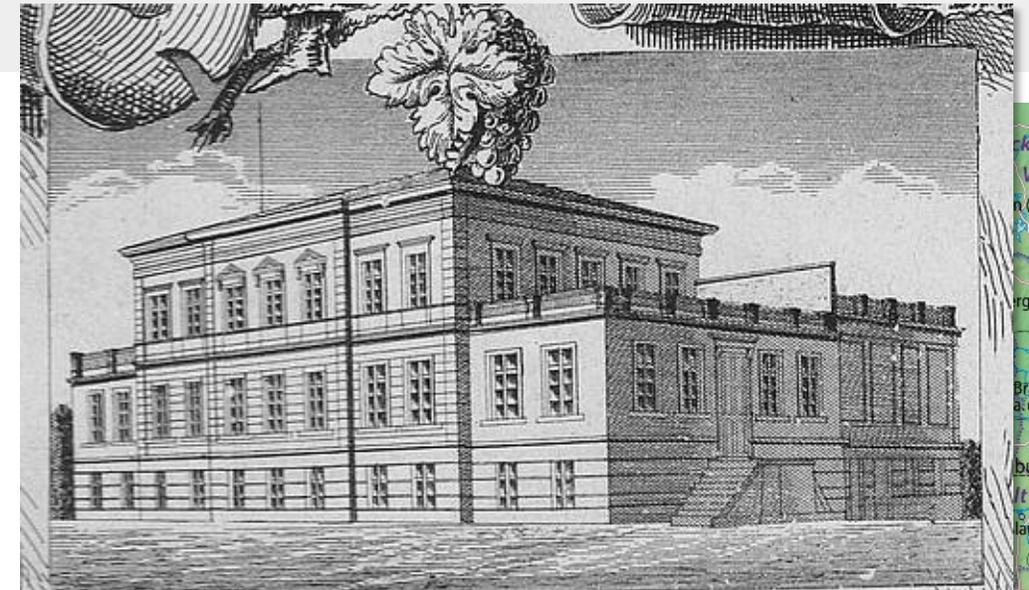
Rector of U Würzburg

**1895**

Offer from U Freiburg (denied)

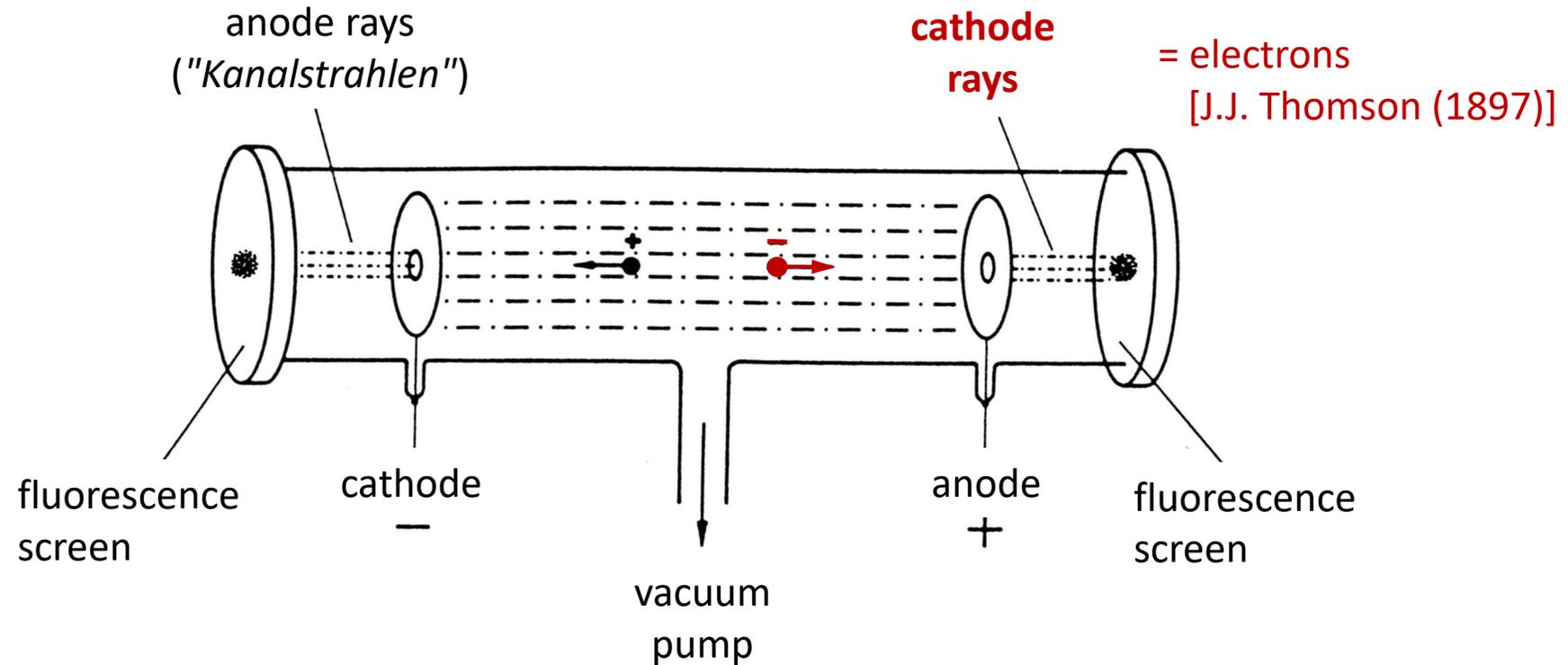
**8 Nov. 1895**

The Discovery of the X-Rays

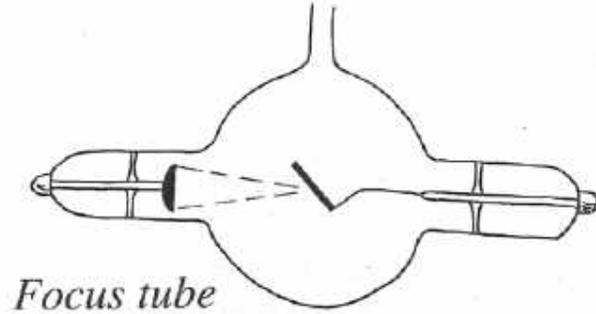
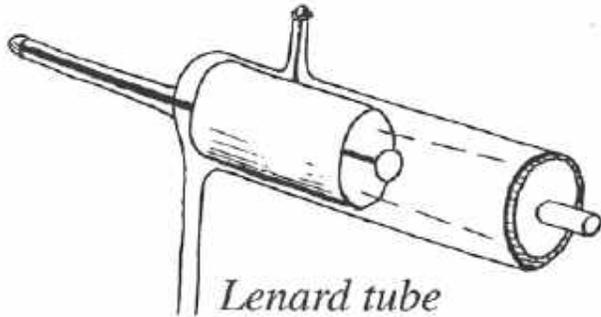
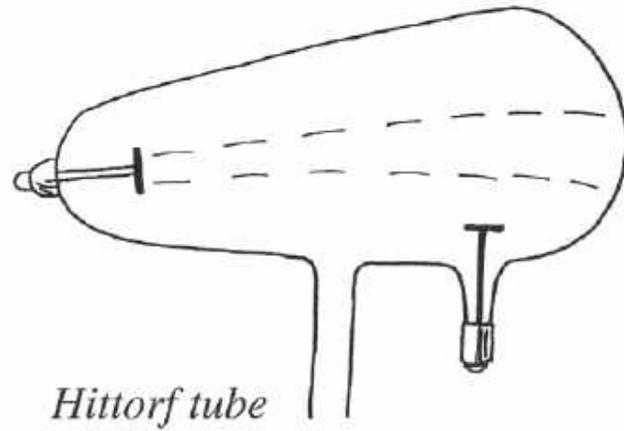
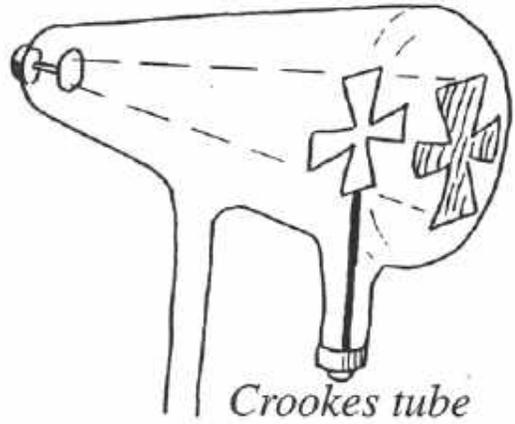


# The Discovery of the X-Rays





preceeding and parallel studies by: Wilhelm Hittorf (Münster)  
William Crookes (London)  
Philipp Lenard (Bonn)



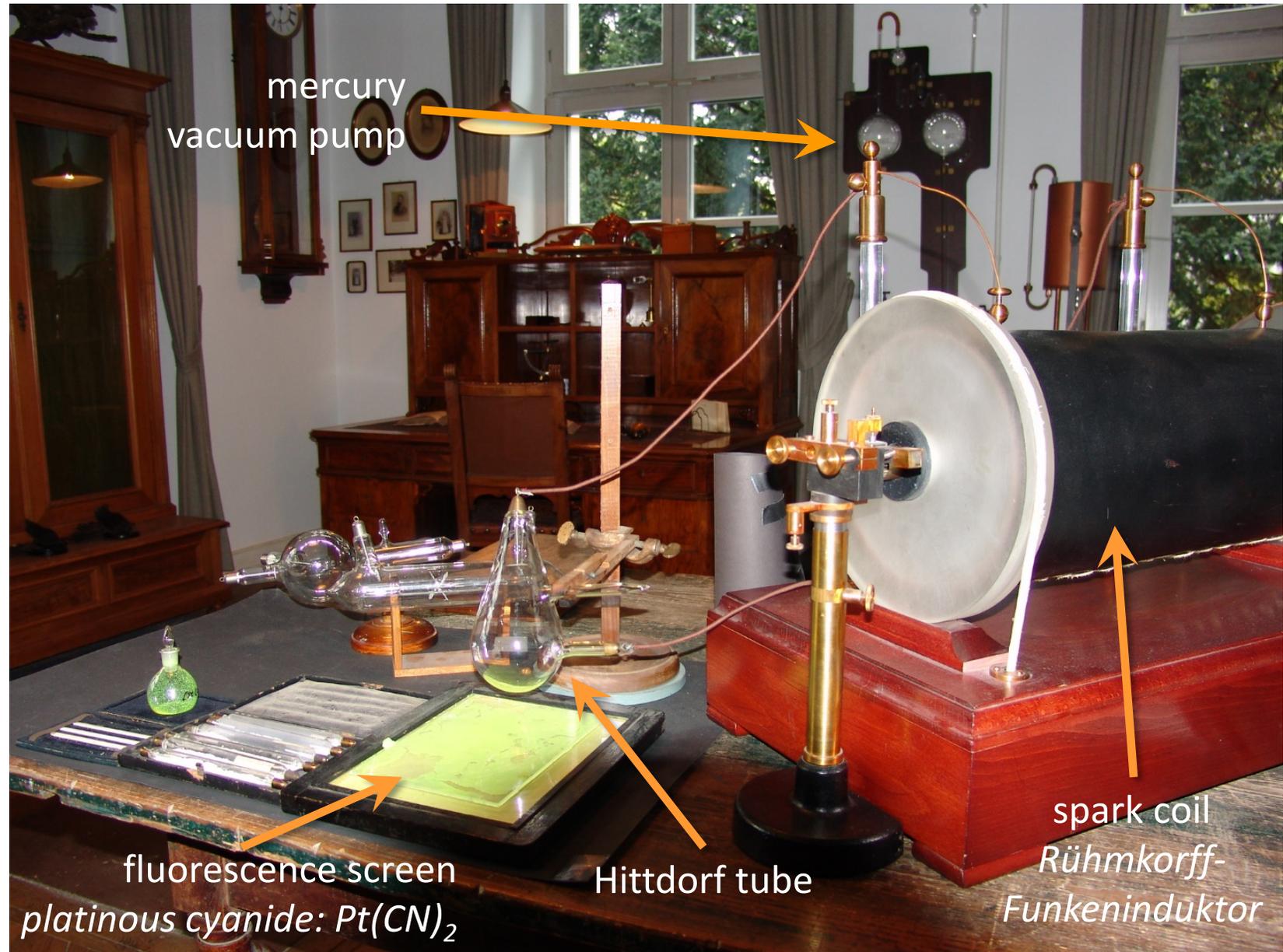
Hittorf tube

(Foto: Röntgen-Gedächtnisstätte Würzburg)

preceding and parallel studies by: Wilhelm Hittorf (Münster)  
William Crookes (London)  
Philipp Lenard (Bonn)

Röntgen's lab in the  
Physikalische Institut

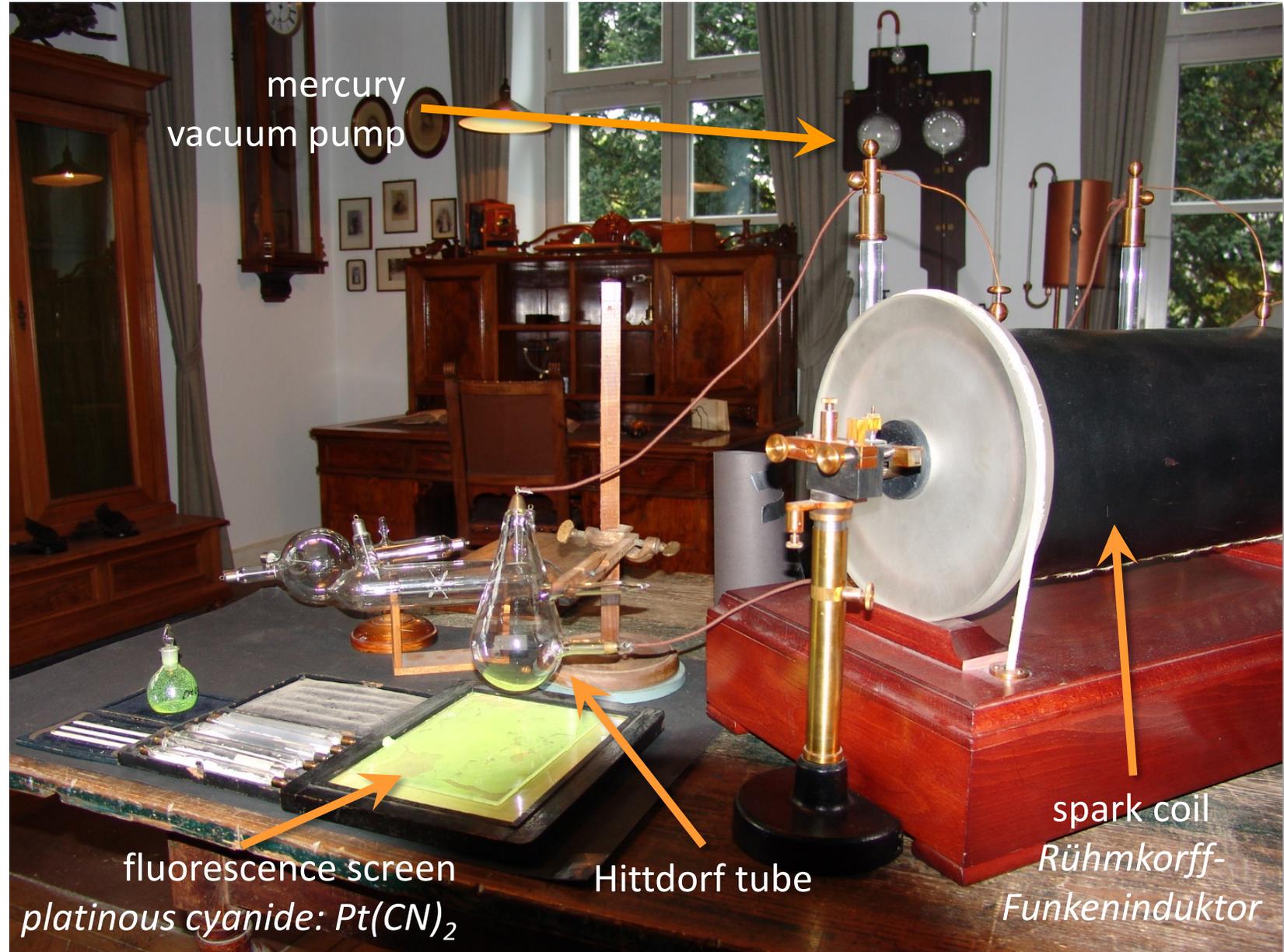
now:  
*Röntgengedächtnisstätte Würzburg and  
EPS Historical Site*



# The Discovery: 8 November 1895

Röntgen's lab in the  
Physikalische Institut

now:  
Röntgengedächtnisstätte Würzburg and  
EPS Historical Site



Röntgen's lab in the  
Physikalische Institut

now:  
Röntgengedächtnisstätte Würzburg and  
EPS Historical Site



Ueber eine neue Art von Strahlen.

von W. C. Röntgen.

(Vorläufige Mittheilung)

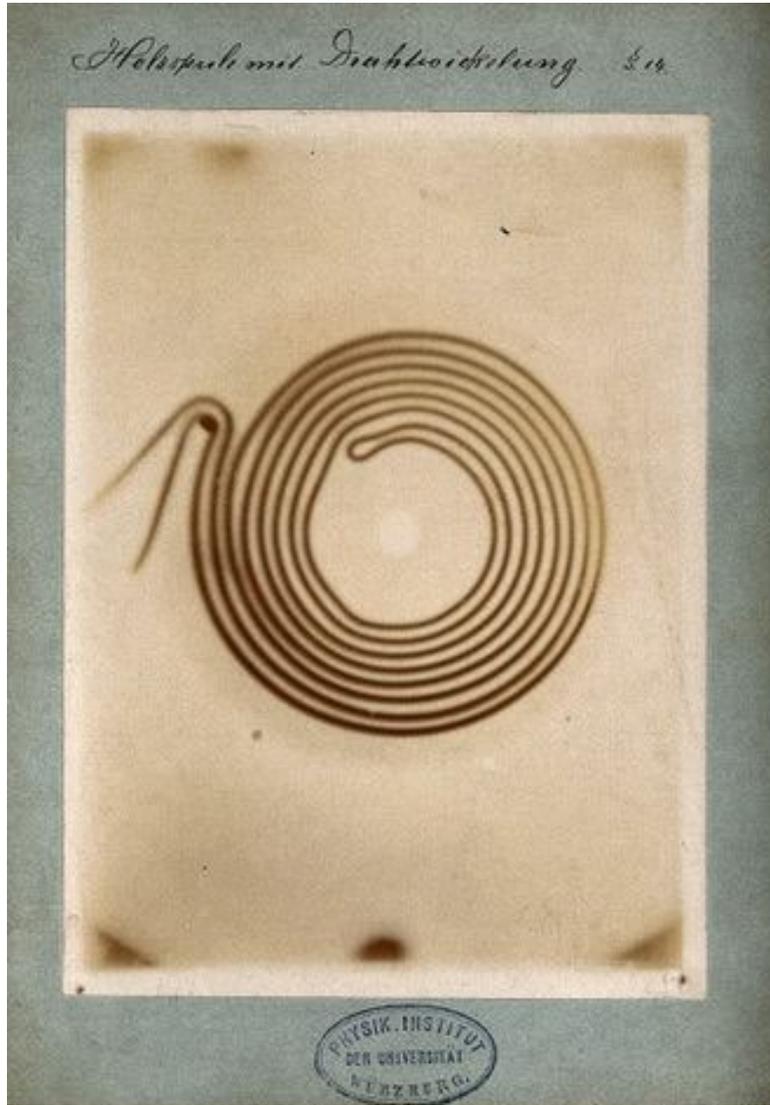
1. Läßt man durch ein Litter'sches Vacuum-  
Röhre, oder einen genügend evacuirten Lenard'  
sehen, Crookes' sehen oder ähnlichen Apparat

die Entladungen eines grossen Ruhmkorff's  
die Röhre gehen und bedeckt den Vorläufer Apparat mit  
einem Mantel aus dünnem

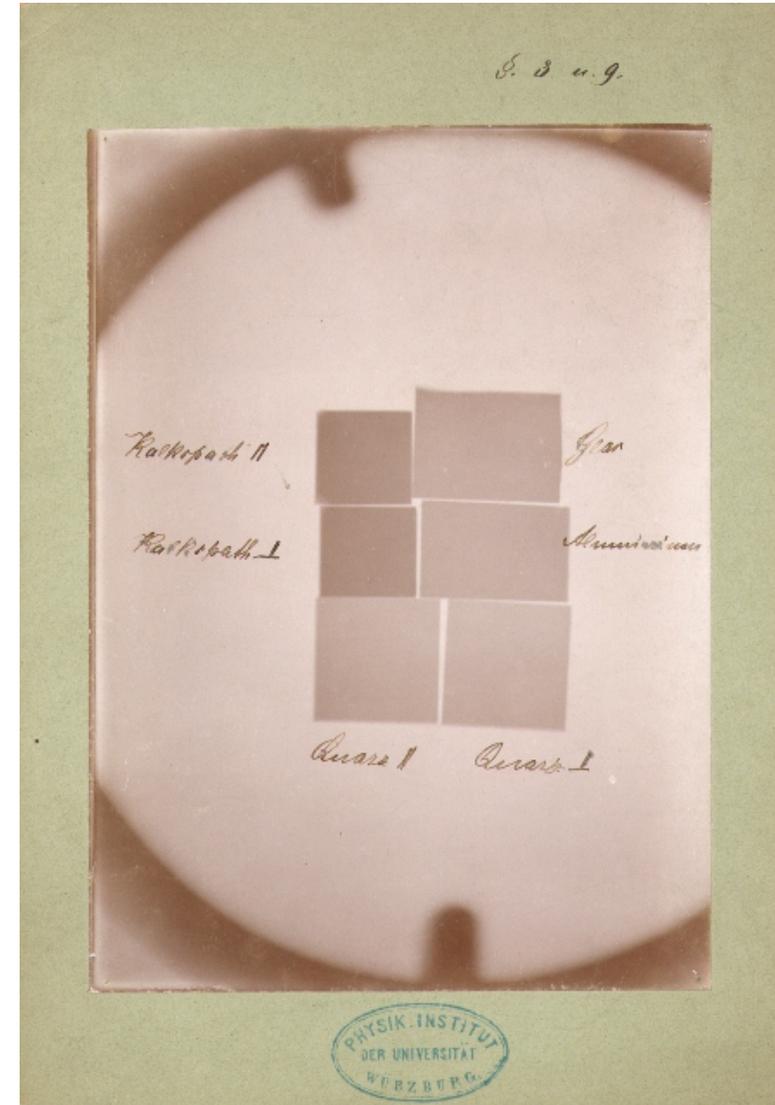
"...und bedeckt die Röhre mit einem [...] Mantel aus dünnem  
Mantel aus dünnem, schwarzen Carton, so  
sieht man in dem vollständig verdunkelten  
Zimmer einen in der Nähe des Apparates  
gebrachten, mit Bariumplatincyanür  
angestrichenen Papierschirm **bei jeder**  
**Entladung hell aufleuchten, fluorescieren,**  
[...]. Die Fluorescenz ist noch in 2m  
Entfernung von der Apparatur bemerkbar."

Man überzeugt sich leicht, dass die Ursache der  
Fluorescenz vom Innern des Vacuumapparates  
und von keiner andern Stelle der Leitung ausgeht.

# The Next 6 Weeks: Systematic Experiments



wire coil on wooden core

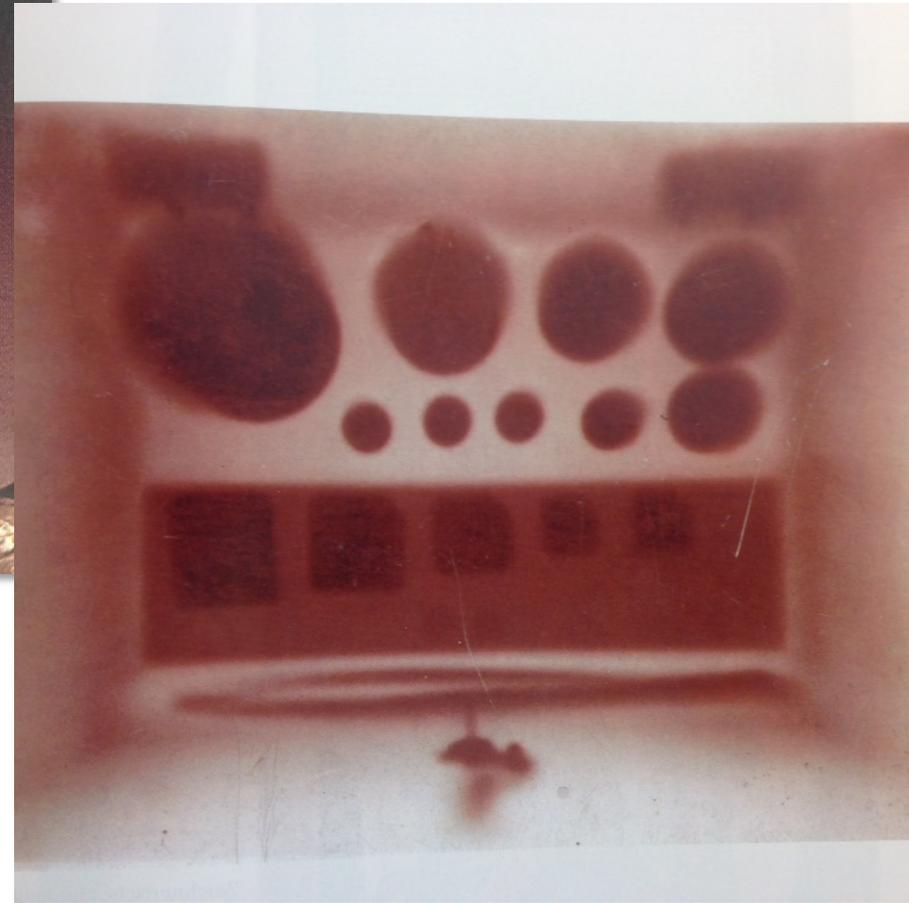


absorption by different minerals  
→ no birefringence in calcite!

# The Next 6 Weeks: Systematic Experiments



X-ray image of a set of weights in a  
**closed** wooden box



# The Next 6 Weeks: Systematic Experiments



22 December 1895:  
Bertha Röntgen's Hand

28 Dec 1895

Preliminary communication "*On a new kind of rays*" to the Physikalisch-Medizinische Gesellschaft in Würzburg

01 Jan 1896

Röntgen sends reprints to his colleagues

## Sitzungs-Berichte

der  
**Physikalisch-medicinischen Gesellschaft**  
zu  
**WÜRZBURG.**

<b>Jahrgang</b> 1895.	Der Abonnementspreis pro Jahrgang beträgt <i>M</i> 4.—. Die Nummern werden einzeln nicht abgegeben. Grössere Beiträge erscheinen in Sonderdrucken.	<b>No. 9.</b>
--------------------------	--	---------------

Verlag der **Stahel'schen** k. Hof- und Universitäts-Buch- und Kunsthandlung in **Würzburg.**

**Inhalt.** *Konrad Rieger*: Demonstration des sogenannten „Vogelkopfkneben“  
*Döbos Janos* aus *Battonya* in *Ungarn* (Fortsetzung), pag. 129. —  
*W. C. Röntgen*: Ueber eine neue Art von Strahlen, pag. 132. —  
*Wilhelm Wislicenus*: 46. Jahresbericht der physikalisch-medizinischen  
Gesellschaft zu Würzburg, pag. 142. — *Mitglieder-Verzeichniss*, pag. 146.

Am 28. Dezember wurde als Beitrag eingereicht:

**W. C. Röntgen: Ueber eine neue Art von Strahlen.**

(Vorläufige Mittheilung.)

1. Lässt man durch eine *Hittorfsche* Vacuumröhre, oder einen genügend evacuirten *Lenard'schen*, *Crookes'schen* oder ähnlichen Apparat die Entladungen eines grösseren *Ruhmkorff's* gehen und bedeckt die Röhre mit einem ziemlich eng anliegenden Mantel aus dünnem, schwarzem Carton, so sieht man in dem vollständig verdunkelten Zimmer einen in die Nähe des Apparates gebrachten, mit *Bariumplatinocyanür* angestrichenen Papierschirm bei jeder Entladung hell aufleuchten, fluoresciren, gleichgültig ob die angestrichene oder die andere Seite des Schirmes dem Entladungsapparat zugewendet ist. Die Fluorescenz ist noch in 2 m Entfernung vom Apparat bemerkbar.

Man überzeugt sich leicht, dass die Ursache der Fluorescenz vom Entladungsapparat und von keiner anderen Stelle der Leitung ausgeht.

2. Das an dieser Erscheinung zunächst Auffallende ist, dass durch die schwarze Cartonhülse, welche keine sichtbaren oder ultravioletten Strahlen des Sonnen- oder des elektrischen Bogenlichtes durchlässt, ein Agens hindurchgeht, das im Stande

**28 Dec 1895**

Preliminary communication "*On a new kind of rays*" to the Physikalisch-Medizinische Gesellschaft in Würzburg

**01 Jan 1896**

Röntgen sends reprints to his colleagues

**05/06/07 Jan 1896**

Newspapers in Wien, London, New York report on the discovery



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**13 Jan 1896**

Invitation by Emperor Wilhelm II. in Berlin



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**05/06/07 Jan 1896**

Newspapers in Wien, London, New York report on the discovery

**13 Jan 1896**

Invitation by Emperor Wilhelm II. in Berlin

**Late Jan/early Feb. 1896**

Publications in *Nature* und *Science*

ON A NEW KIND OF RAYS.<sup>1</sup>

1) A DISCHARGE from a large induction coil is passed through a Hittorf's vacuum tube, or through a well-exhausted Crookes' or Lenard's tube. The tube is surrounded by a fairly close-fitting shield of black paper; it is then possible to see, in a completely darkened room, that paper covered on one side with barium platino-cyanide lights up with brilliant fluorescence when brought into the neighbourhood of the tube, whether the painted side or the other be turned towards the tube. The fluorescence is still visible at two metres distance. It is easy to show that the origin of the fluorescence lies within the vacuum tube.

(2) It is seen, therefore, that some agent is capable of penetrating black cardboard which is quite opaque to ultra-violet light, sunlight, or arc-light. It is therefore of interest to investigate how far other bodies can be penetrated by the same agent. It is readily shown that all bodies possess this same transparency, but in very varying degrees. For example, paper is very transparent; the fluorescent screen will light up when placed behind a book of a thousand pages; printer's ink offers no marked resistance. Similarly the fluorescence shows behind two packs of cards; a single card does not visibly diminish the brilliancy of the light. So, again, a single thickness of tinfoil hardly casts a shadow on the screen; several have to be superposed to produce a marked effect. Thick blocks of wood are still transparent. Boards of pine two or three centimetres thick absorb only very little. A piece of sheet aluminium, 15 mm. thick, still allowed the X-rays (as I will call the rays,

<sup>1</sup> By W. C. Röntgen. Translated by Arthur Stanton from the *Sitzungsberichte der Würzburger Physik-med. Gesellschaft*, 1895.

NO. 1369, VOL. 53]

W.C. Röntgen,  
*Nature* 53, 274 (1896)



FIG. 1.—Photograph of the bones in the fingers of a living human hand. The third finger has a ring upon it.

**23 Jan 1896**

Lecture at the  
Physikalisch-Medizinische Gesellschaft  
in Würzburg



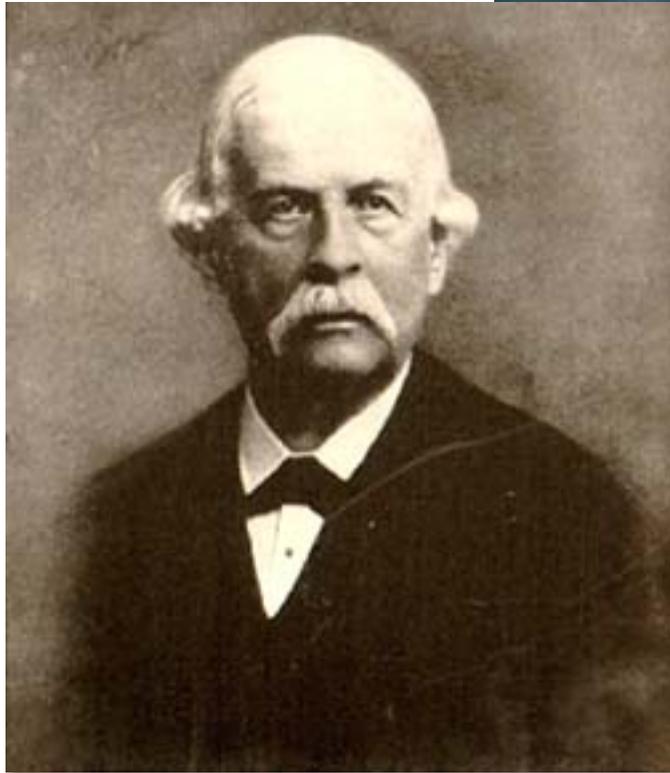
**23 Jan 1896**

Lecture at the  
Physikalisch-Medizinische Gesellschaft  
in Würzburg



**23 Jan 1896**

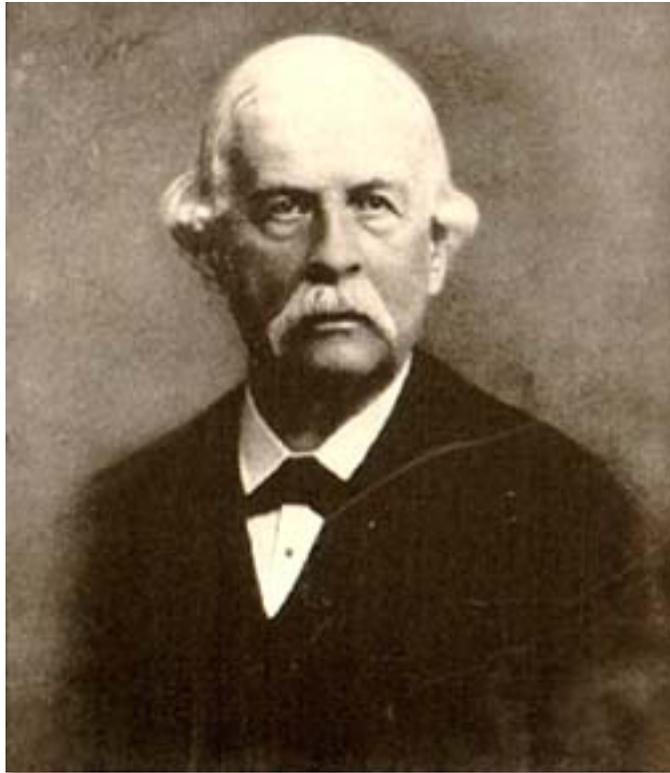
Lecture at the  
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in Würzburg



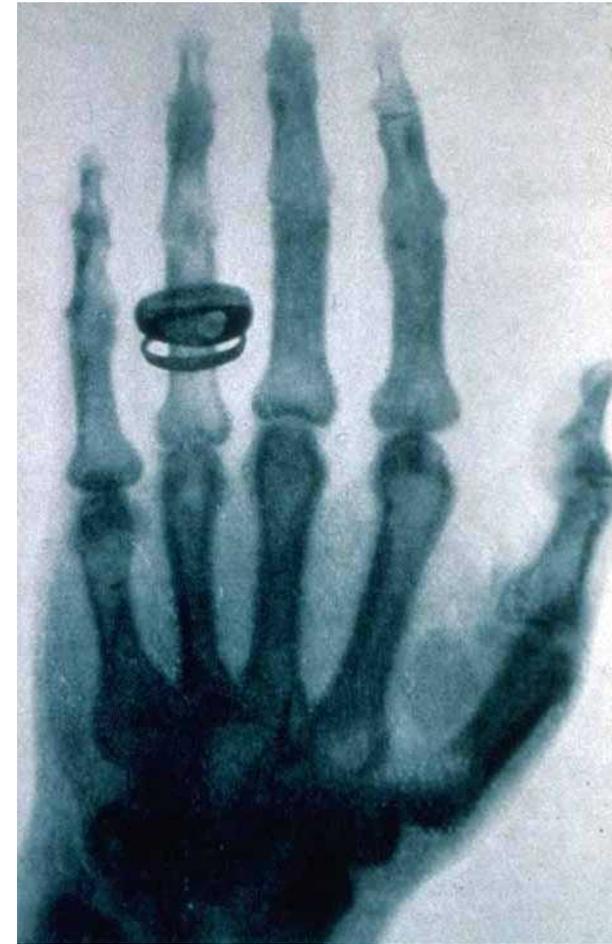
Geheimrath Rudolf Albert von Kölliker...

**23 Jan 1896**

Lecture at the  
Physikalisch-Medizinische Gesellschaft  
in Würzburg



Geheimrath Rudolf Albert von Kölliker...



...and his hand

10 Dec 1901

W.C. Röntgen becomes the first recipient of the Nobel Prize in Physics:

*"... to those who, during the preceding year, have conferred the greatest benefit to humankind."*

(from Alfred Nobel's last will)

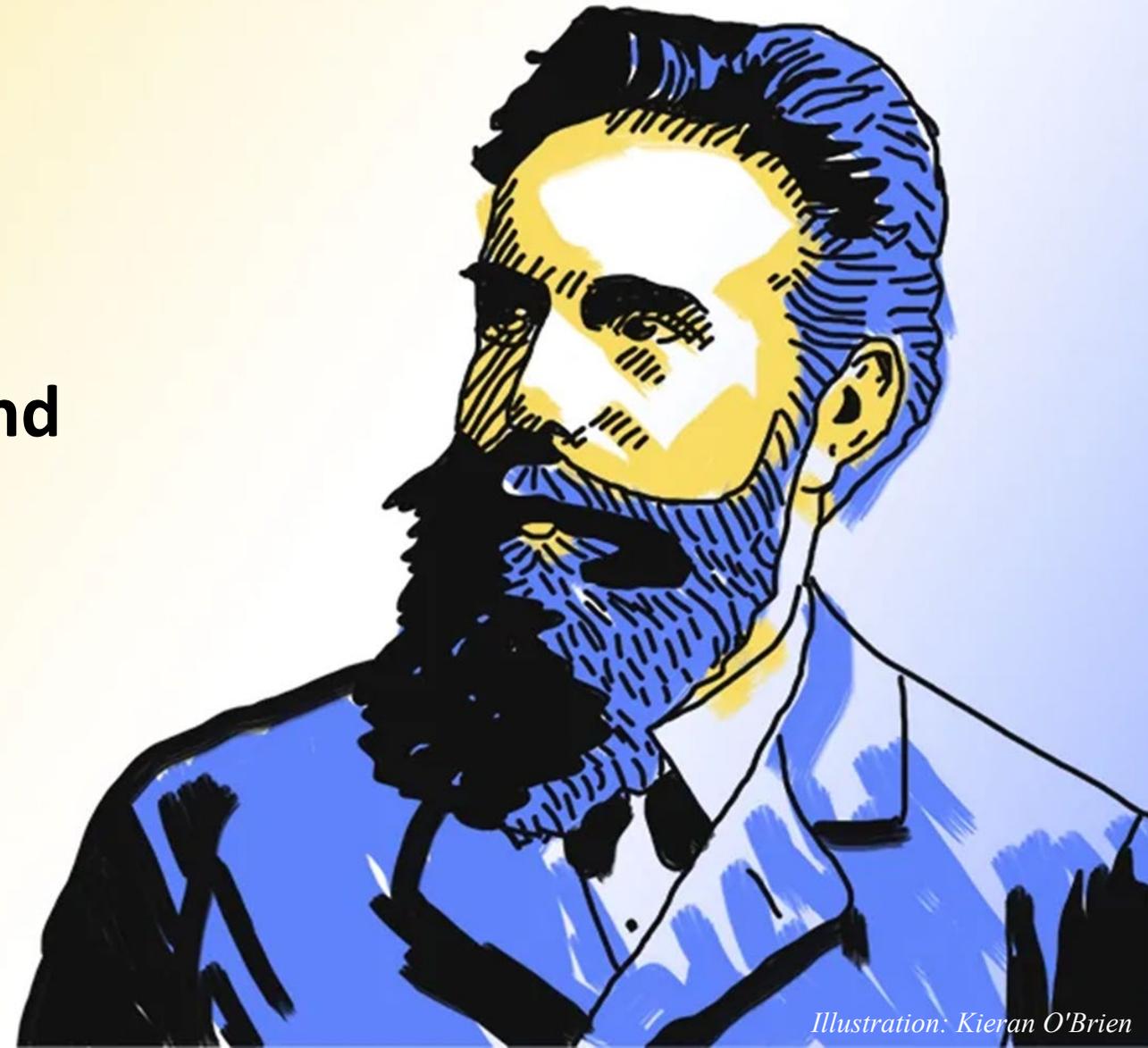
Röntgen declines to give a Nobel lecture.

In his will Röntgen donates his prize money (50.000 Swedish Crowns) to the University of Würzburg.

Röntgen never considered filing a patent for his discovery.



# Scientific Impact and Beyond





**Physics**  
**Chemistry**  
**Medicine**

- 1901** W. C. Röntgen  
Discovery of the x-rays
- 1914** M. von Laue  
X-ray diffraction in crystals
- 1915** W. H. Bragg/W. L. Bragg  
Determination of crystal structures
- 1917** W. G. Barkla  
Characteristic radiation of the elements
- 1924** K. M. G. Siegbahn  
X-ray spectroscopy
- 1927** A. H. Compton  
X-ray scattering off electrons
- 1936** P. Debye  
Diffraction of x-rays and electrons by gases
- 1946** H. J. Muller  
Discovery of x-ray-induced mutations
- 1962** M. Perutz/J. Kendrew  
Structure of hemoglobin
- 1962** J. Watson/M. Wilkins/F. Crick  
Double-helix structure of DNA
- 1964** D. C. Hodgkin  
Structure of biochemical compounds
- 1976** W. N. Lipscomb  
Structure of boranes
- 1979** A. M. Cormack/G. N. Hounsfield  
Computer-based tomography
- 1981** K. M. Siegbahn  
High resolution electron spectroscopy
- 1985** H. Hauptman/J. Karle  
Direct methods for crystal structure determination
- 1988** J. Deisenhofer/R. Huber/H. Michel  
Three-dimensional structure of a photosynthetic reaction center
- 1997** P. D. Boyer/J. E. Walker  
Mechanism of ATP synthesis
- 2002** R. Giacconi  
discovery of cosmic x-ray sources
- 2003** P. Agre/R. MacKinnon  
Discoveries concerning channels in cell membranes
- 2006** R. D. Kornberg  
Molecular basis of eukaryotic transcription
- 2009** V. Ramakrishnan/T. A. Steitz/A. E. Yonath  
Structure and function of the ribosome
- 2011** D. Shechtman  
Discovery of quasicrystals

# X-Ray Imaging: Revealing the Invisible

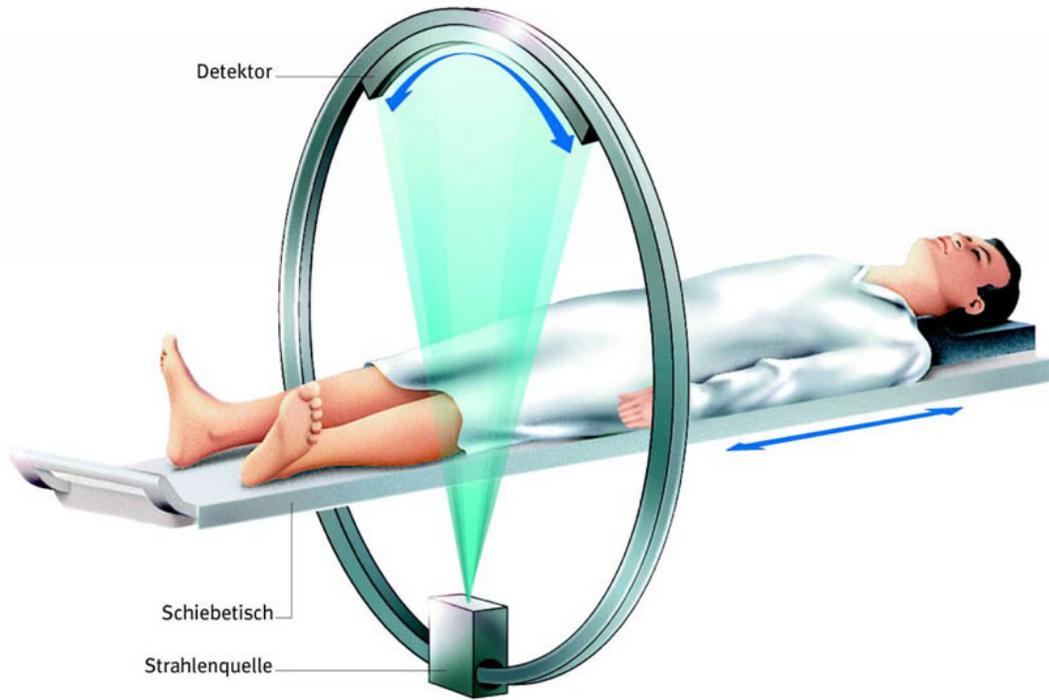


1895



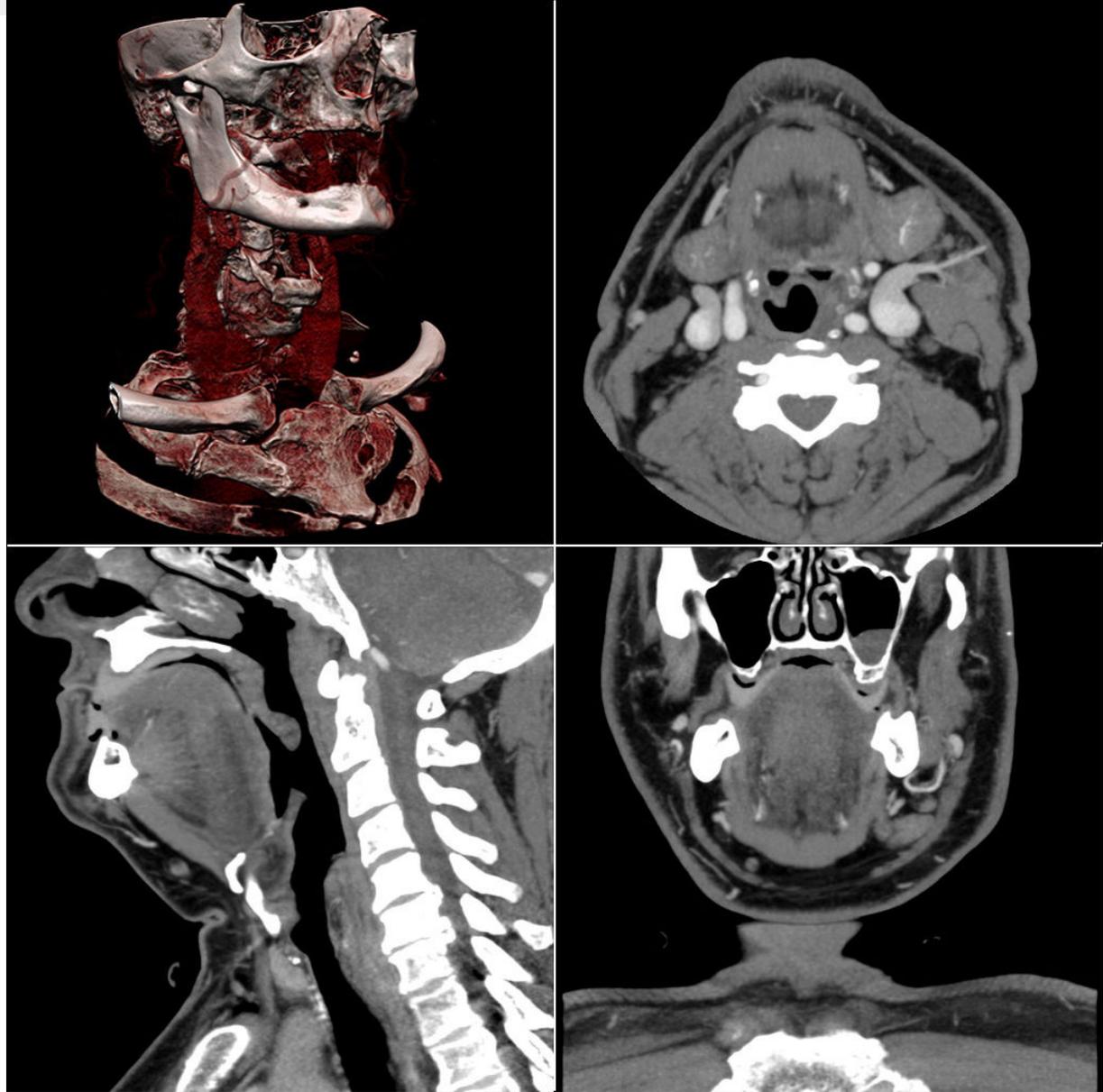
...and today

## Computer Tomography (CT)



several 100 x-ray images taken under varying angle

→ numerical reconstruction in 3D



# X-Ray Imaging: Revealing the Invisible

Röntgen's hunting rifle



*Materialfehler des  
Damastlaufes*

*Materialfehler des  
Damastlaufes*

*ein Deckplättchen  
ein Pfropf  
ein Deckplättchen  
ein Pfropf  
9 Rölller  
9 Rölller*

*ein Pfropf  
ein Pfropf*

*Vertiefung  
Vertiefung  
Pulver  
Pulver*

*Übergangsstelle von dem  
weiteren zu dem engeren  
Teile des Rohres*

*Übergangsstelle von dem  
weiteren zu dem engeren  
Teile des Rohres*

*Zwei Deckplättchen  
zwei Deckplättchen*

*Kugel mit Gussansatz  
Kugel mit Gussansatz*

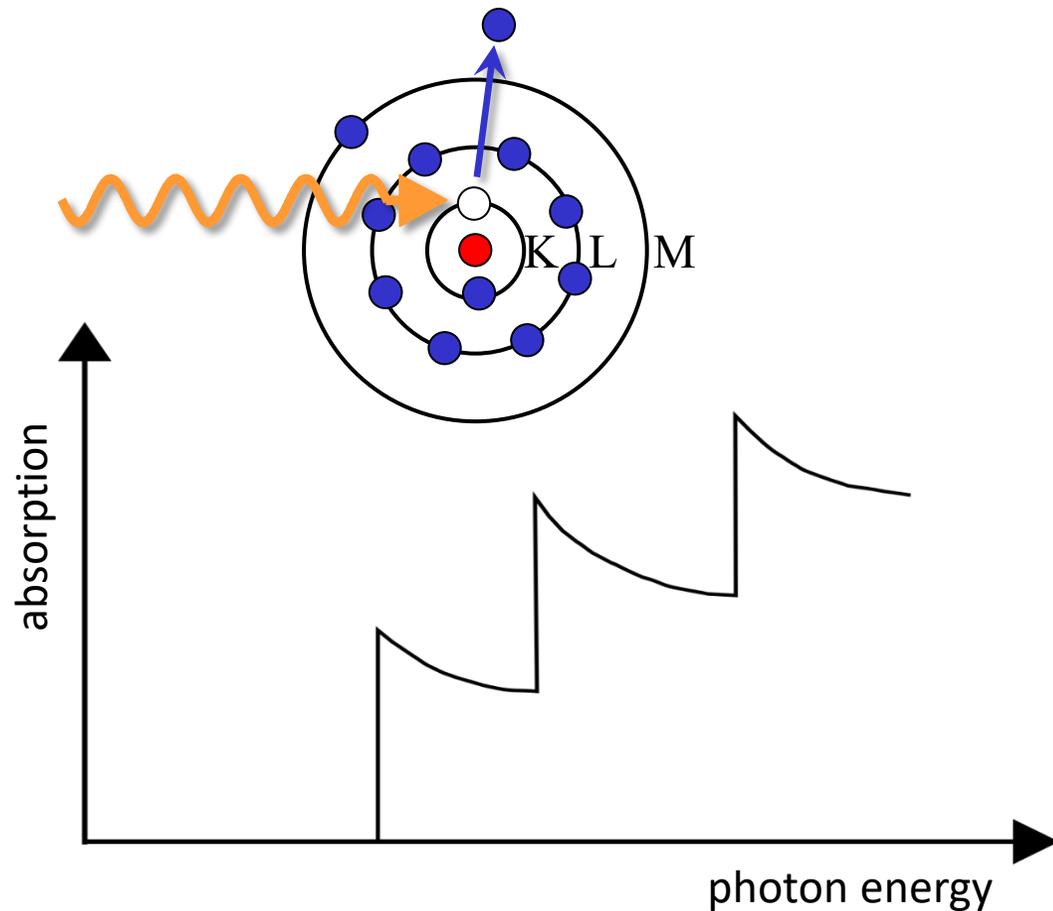
*zwei Pfropfen  
zwei Pfropfen*

*eingeschlagene Zahl  
eingeschlagene Zahl*

*Lefauchaux-Zünder  
Lefauchaux-Zünder*

Where does the contrast in x-ray imaging come from?

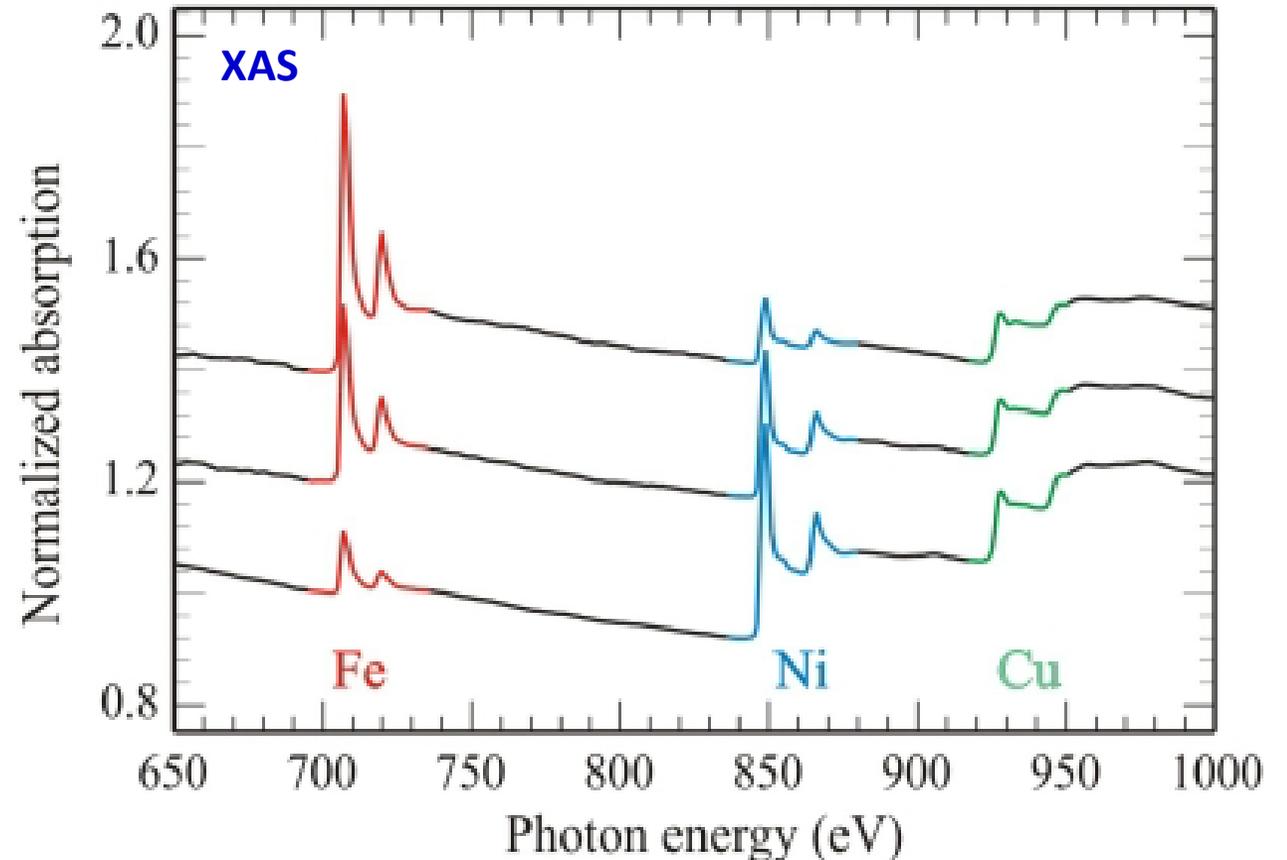
- atomic inner shell excitations
- **element-specific x-ray absorption edges**



## Zoo of x-ray spectroscopic techniques

for, e.g., materials science and quantum matter research:

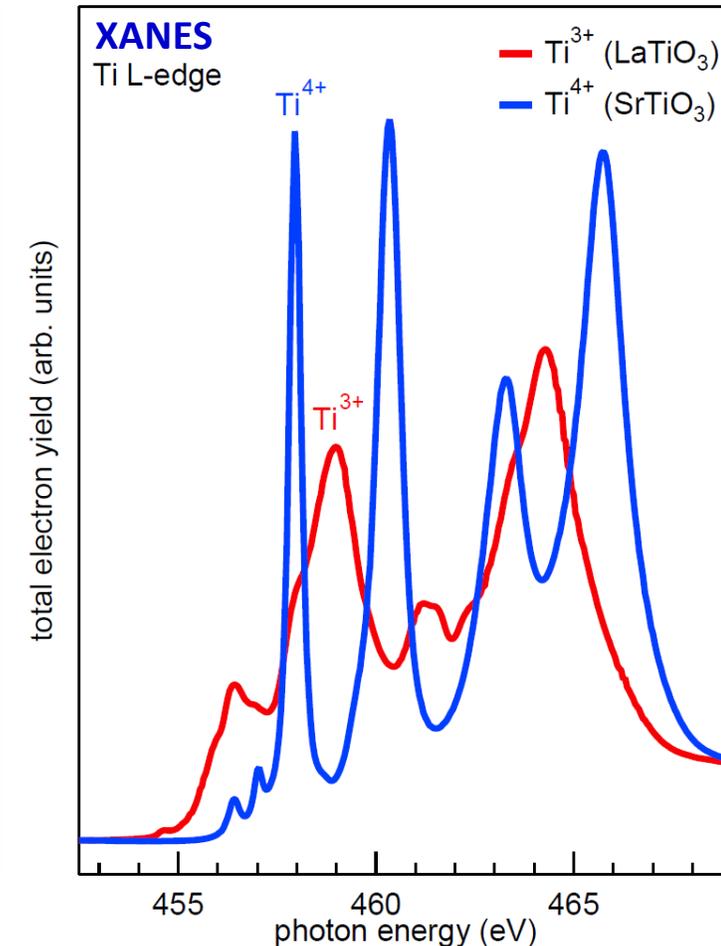
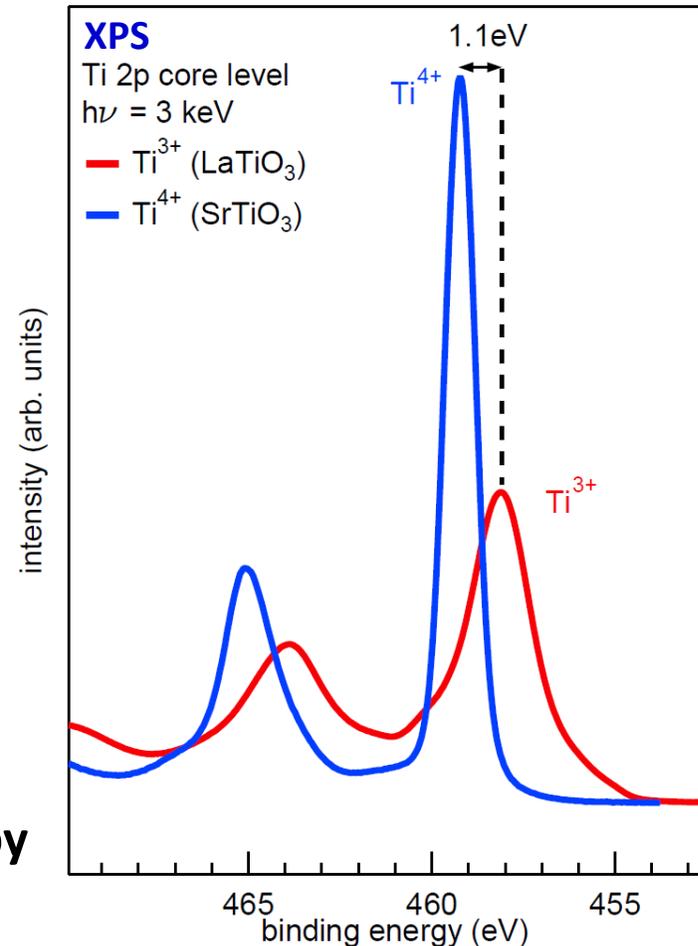
- **X-ray absorption**  
(**XAS**, XANES, EXAFS,...)
- **X-ray fluorescence**  
(XF, XES, EDX, WDX,...)
- **Photoelectron spectroscopy**  
(XPS, ESCA, HAXPES, ARPES, ResPES,...)
- **Inelastic x-ray scattering**  
(IXS, RIXS, Compton scattering,...)
- **Spectromicroscopy & microspectroscopy**  
(STXM, PEEM,...)
- and many more...



## Zoo of x-ray spectroscopic techniques

for, e.g., materials science and quantum matter research:

- **X-ray absorption**  
(**XAS**, **XANES**, EXAFS,...)
- **X-ray fluorescence**  
(XF, XES, EDX, WDX,...)
- **Photoelectron spectroscopy**  
(**XPS**, ESCA, HAXPES, ARPES, ResPES,...)
- **Inelastic x-ray scattering**  
(IXS, RIXS, Compton scattering,...)
- **Spectromicroscopy & microspectroscopy**  
(STXM, PEEM,...)
- and many more...

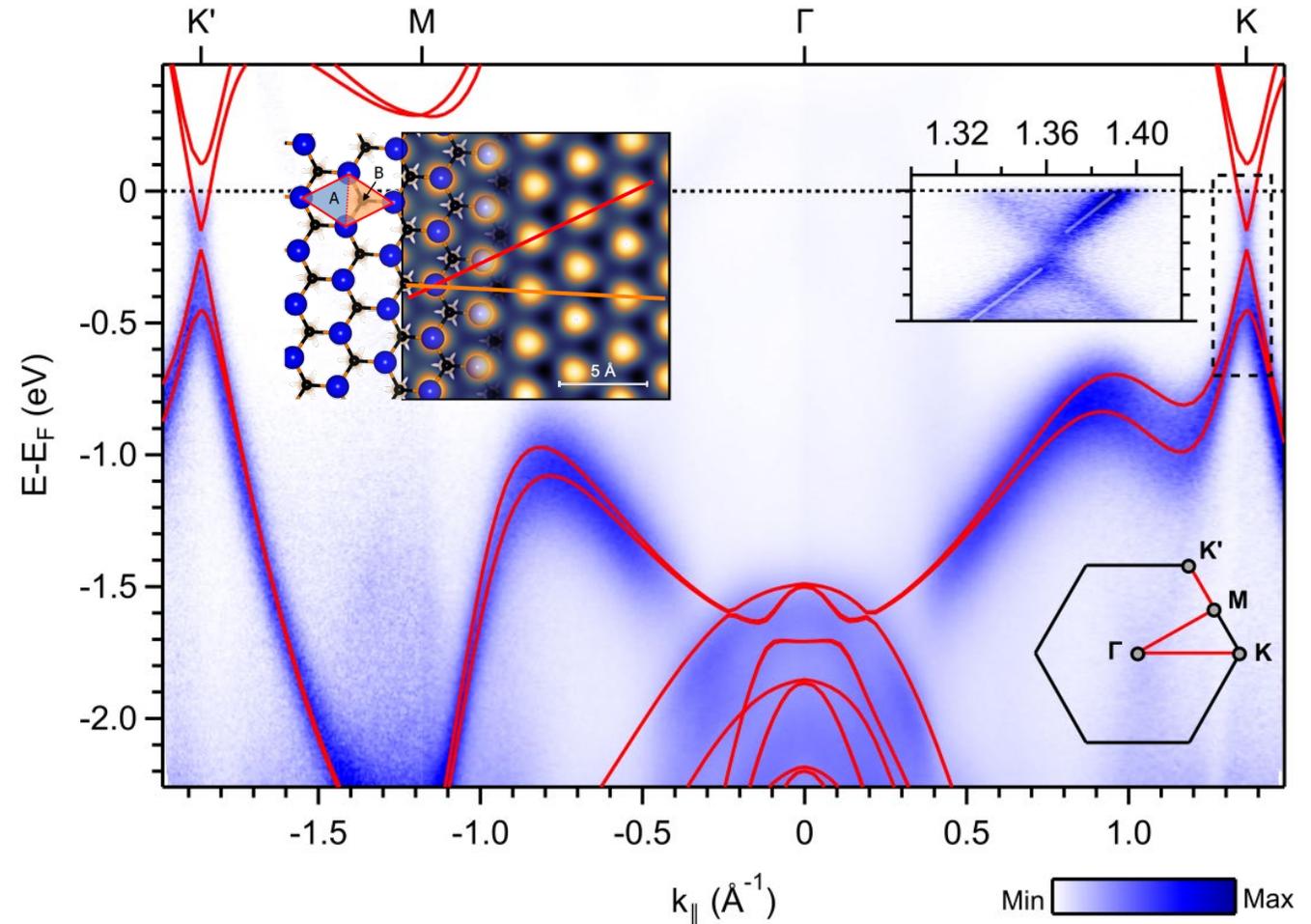


→ elemental composition  
→ chemical valency

**Zoo of x-ray spectroscopic techniques**  
for, e.g., materials science and  
quantum matter research:

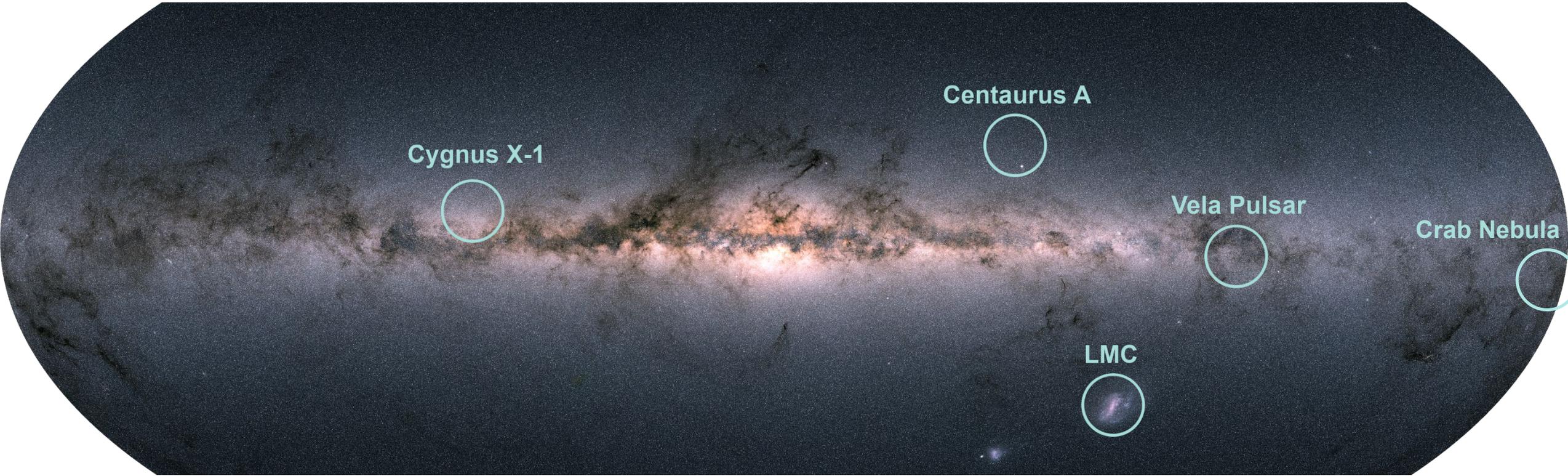
- **X-ray absorption**  
(XAS, XANES, EXAFS,...)
- **X-ray fluorescence**  
(XF, XES, EDX, WDX,...)
- **Photoelectron spectroscopy**  
(XPS, ESCA, HAXPES, **ARPES**, ResPES...)
- **Inelastic x-ray scattering**  
(IXS, RIXS, Compton scattering,...)
- **Spectromicroscopy & microspectroscopy**  
(STXM, PEEM,...)
- and many more...

**ARPES of "indenene" (1 ML In/4H-SiC)**

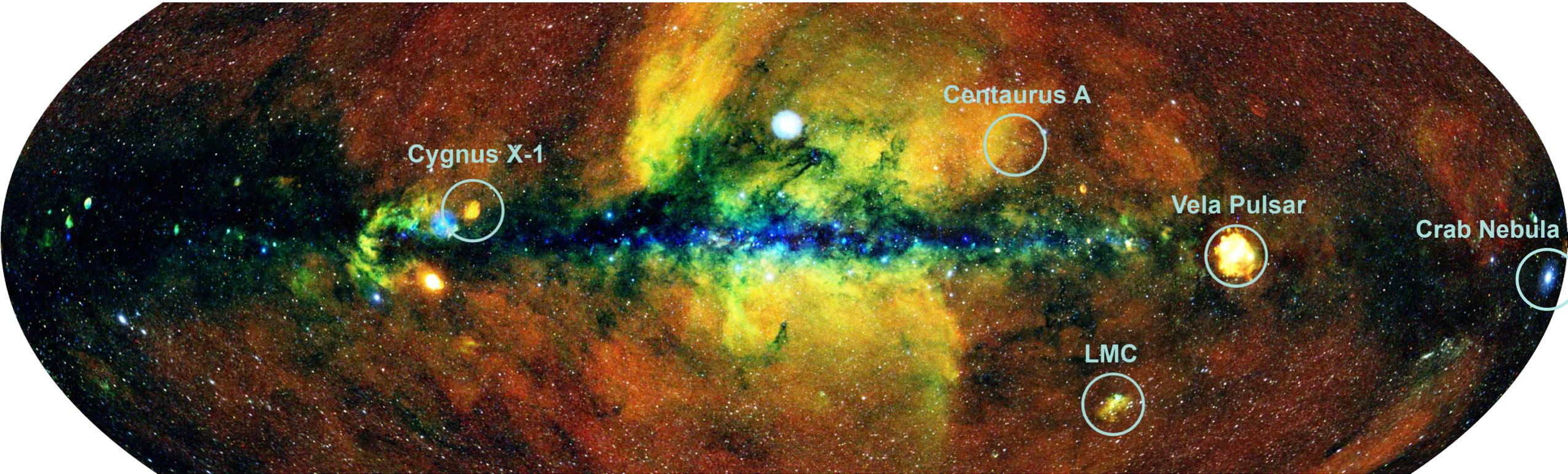


→ **electronic band structure**

## Optical map of the sky

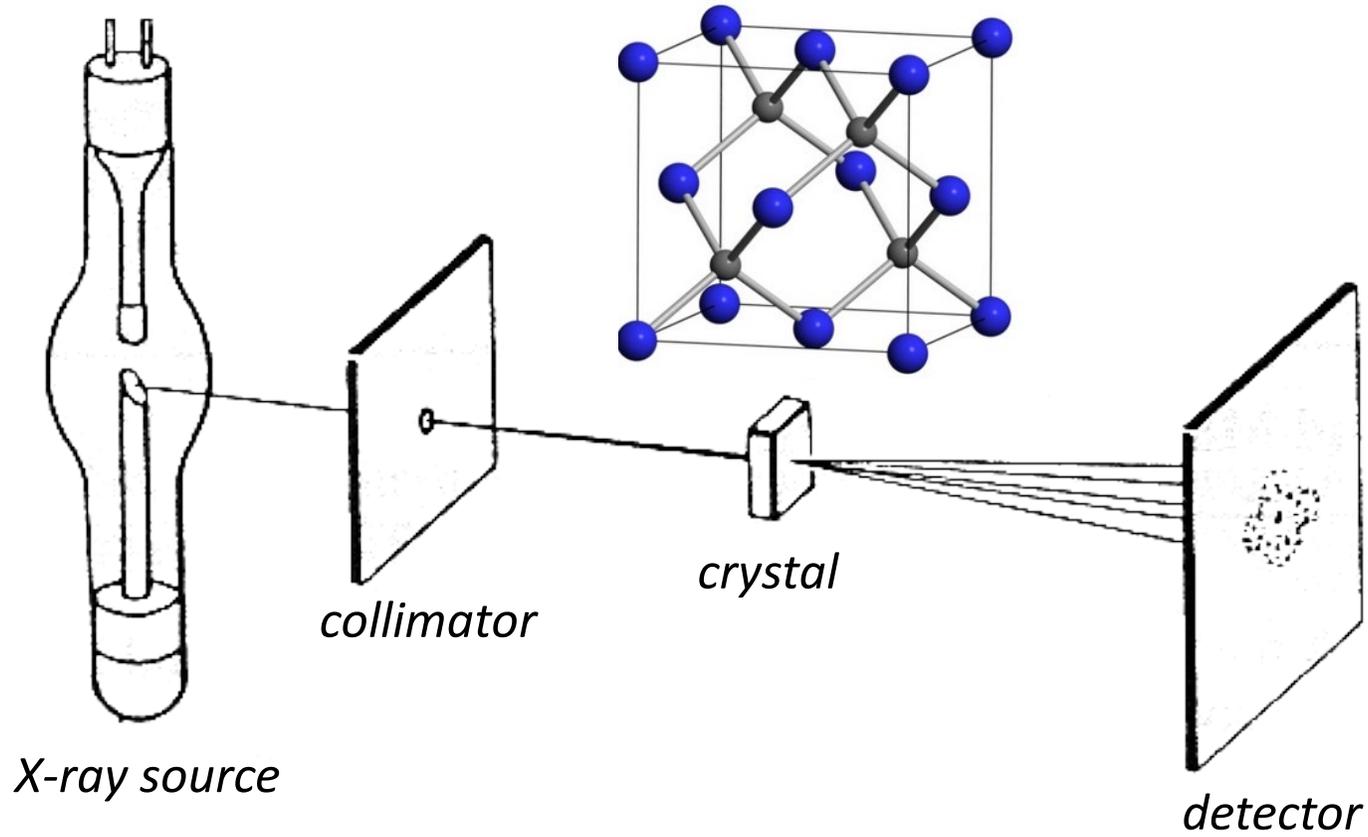


X-ray map of the sky (0.3 – 2.3 keV)

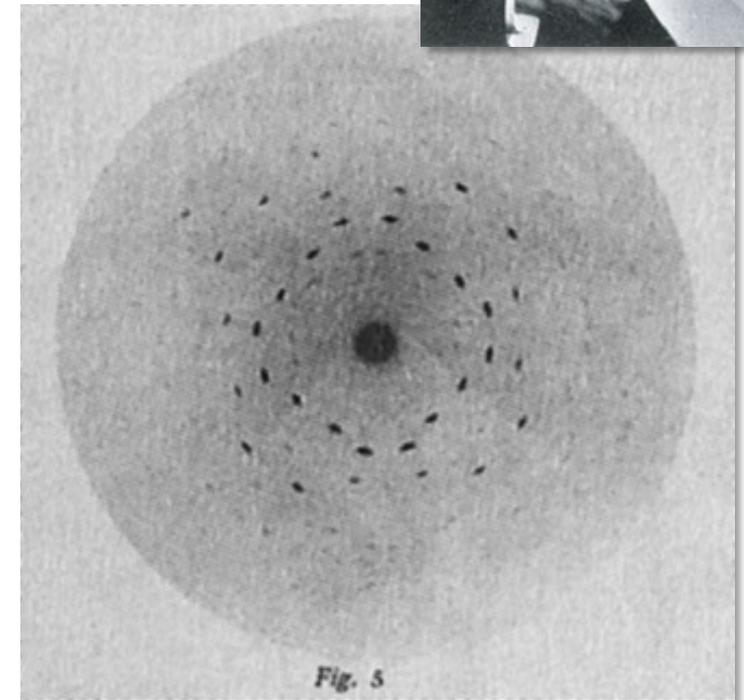


data taken by the x-ray telescope **eROSITA**  
on board the German-Russian satellite observatory **Spektr-RG**  
(red to blue = increasing photon energy)

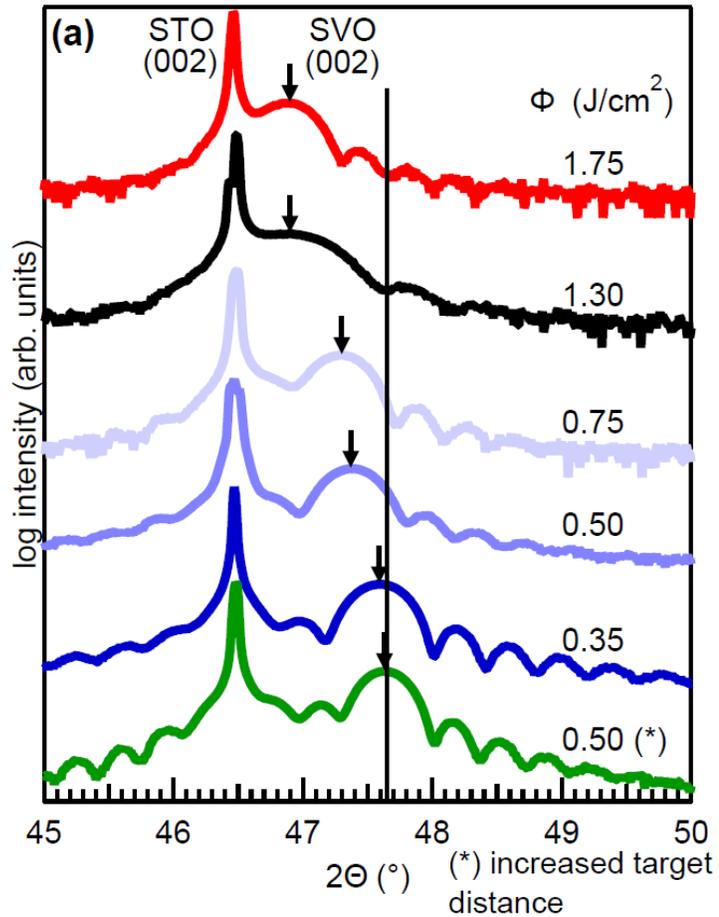
X-rays are electromagnetic waves



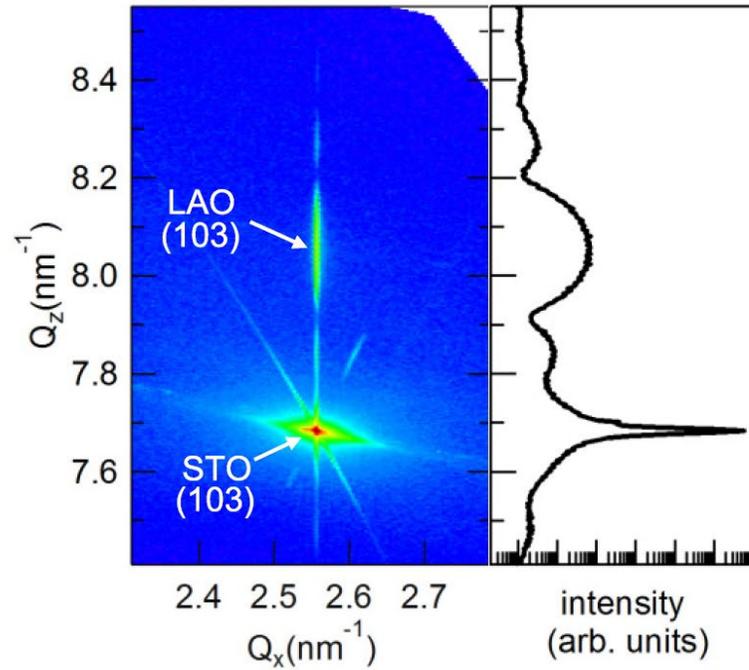
**Max von Laue**  
Physics Nobel Prize  
1914



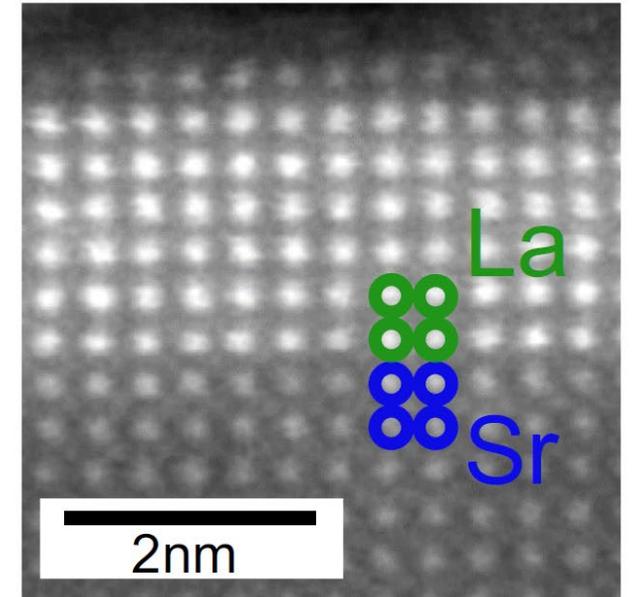
## X-ray diffraction (XRD) in materials science



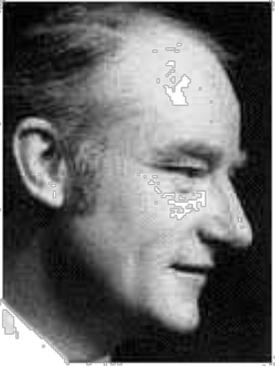
**XRD of an oxide heterostructure**  
(SrVO<sub>3</sub>/SrTiO<sub>3</sub>)



**reciprocal space map**  
(LaAlO<sub>3</sub>/SrTiO<sub>3</sub>)



## Structural biology: Double helix structure of the DNA (1953)



Francis Crick



James Watson



Maurice Wilkins



Rosalind Franklin

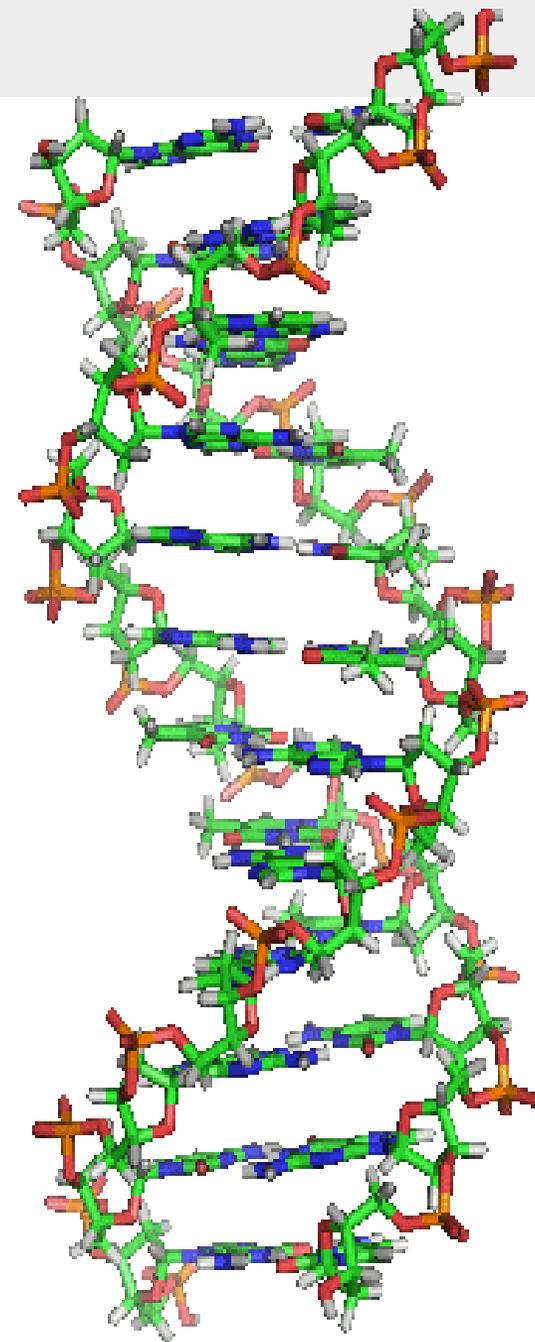
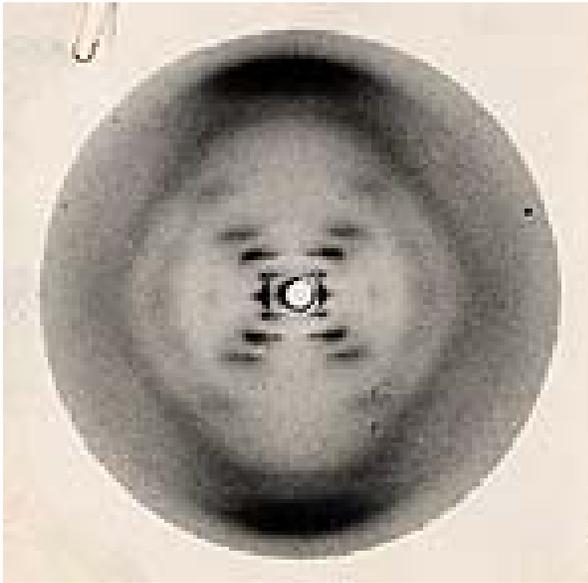
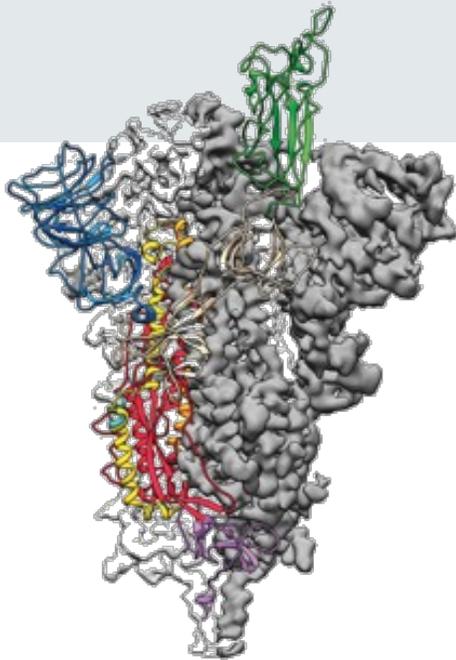
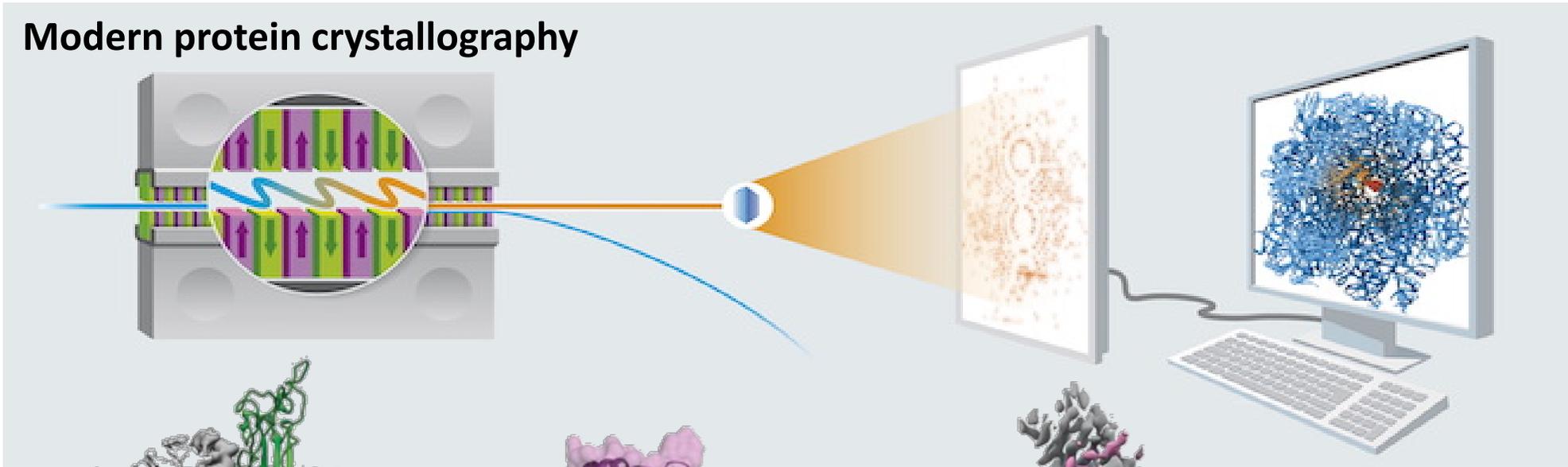
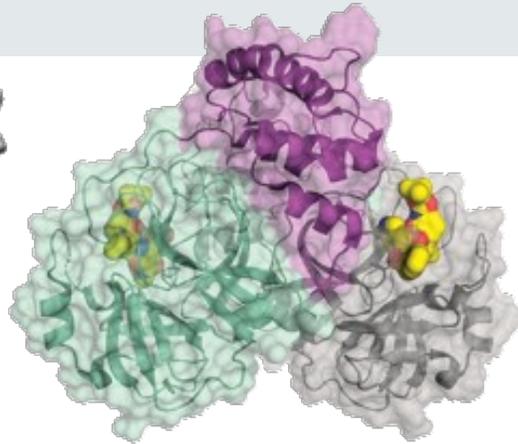


Illustration: DESY, Cyprian Lothringer

## Modern protein crystallography



spike protein



main protease

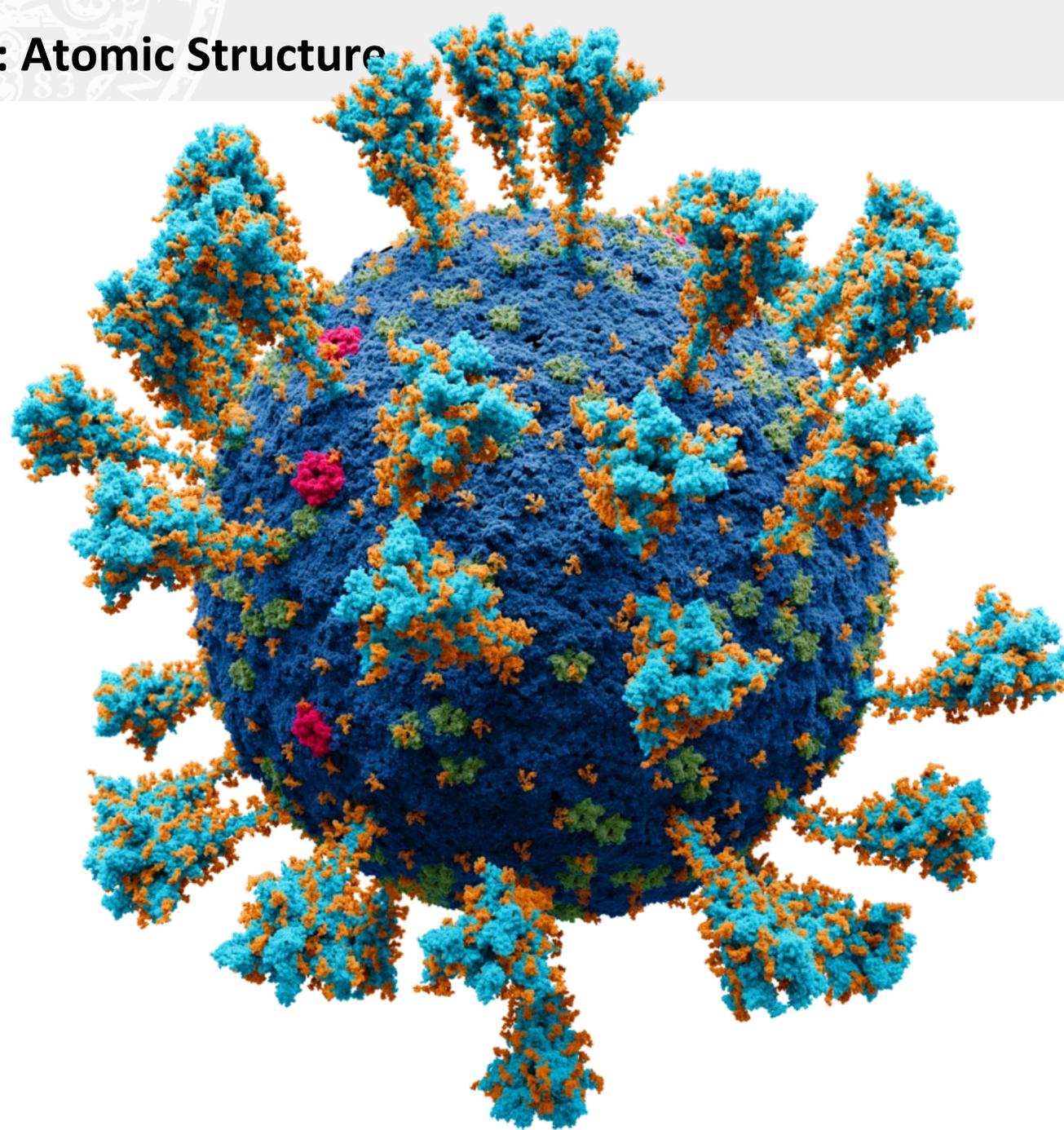


RNA polymerase

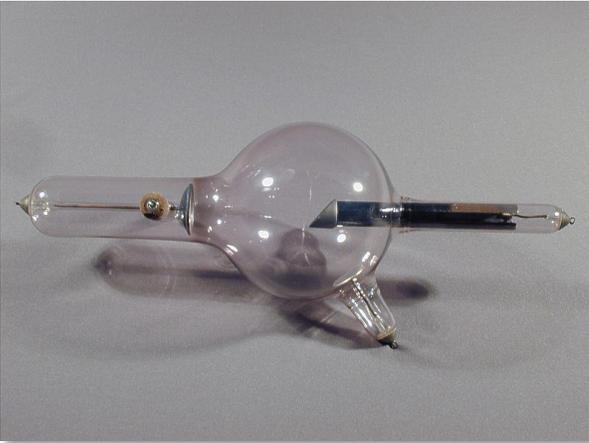
Credits:  
J. McLellan/U Texas at Austin (spike)  
H. Tabermann/HZB (protease)  
Science (polymerase)

## SARS-CoV-2 virus

atomically resolved  
3D structure model



1895



2020's



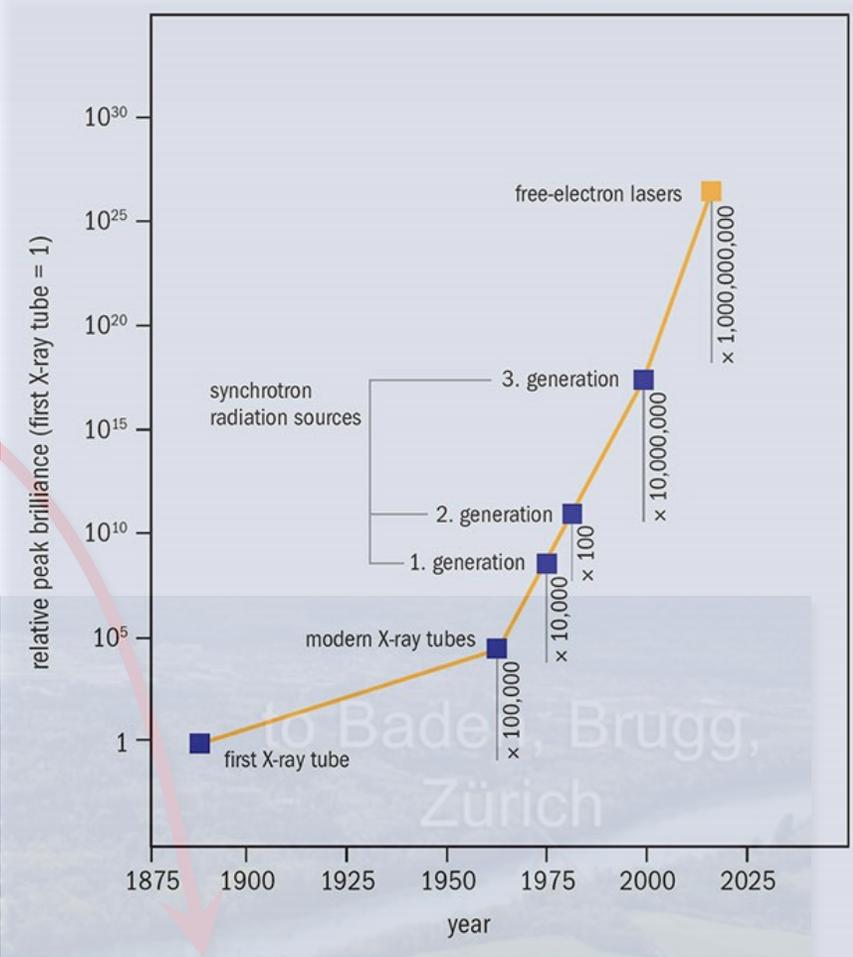
# X-Ray Technology: Sources & Detectors



**1895**



**2020's**



to Koblenz and  
Germany

**SwissFEL**

**SLS**

to Böttstein

**PSI site**

to Villigen



Still going strong at 125+1 years !