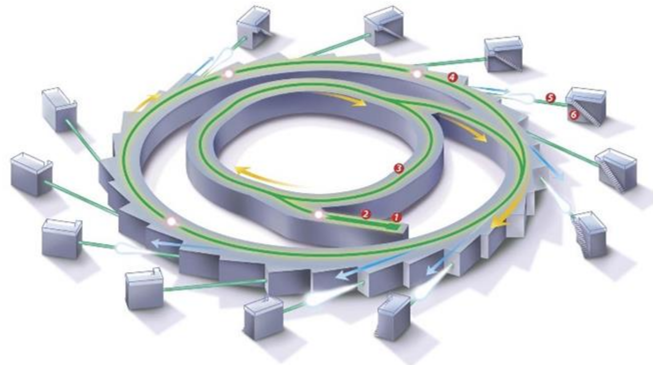

Dünyanın En Parlak Sinkrotron Işınım Tesisi PETRAIII: Bilim ve Teknoloji Uygulamaları

Doç.Dr. Didem KETENOĞLU

Ankara Üniversitesi
Fizik Mühendisliği Bölümü
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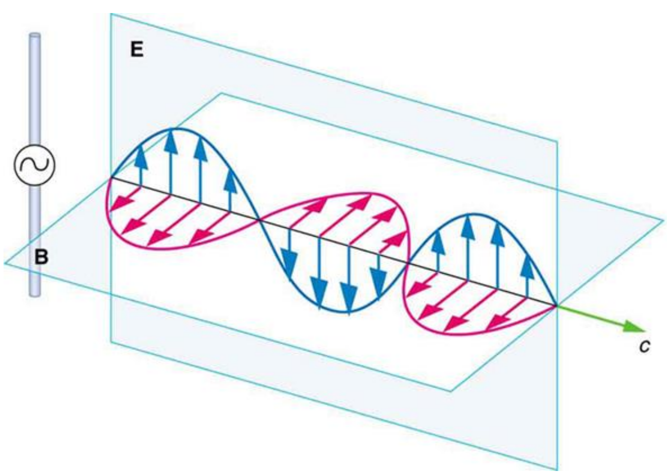
65.Yılında DESY: Ankara Üniversitesi-DESY İlişkileri Konferansı
26 Şubat 2025, Ankara Üniversitesi, Ankara

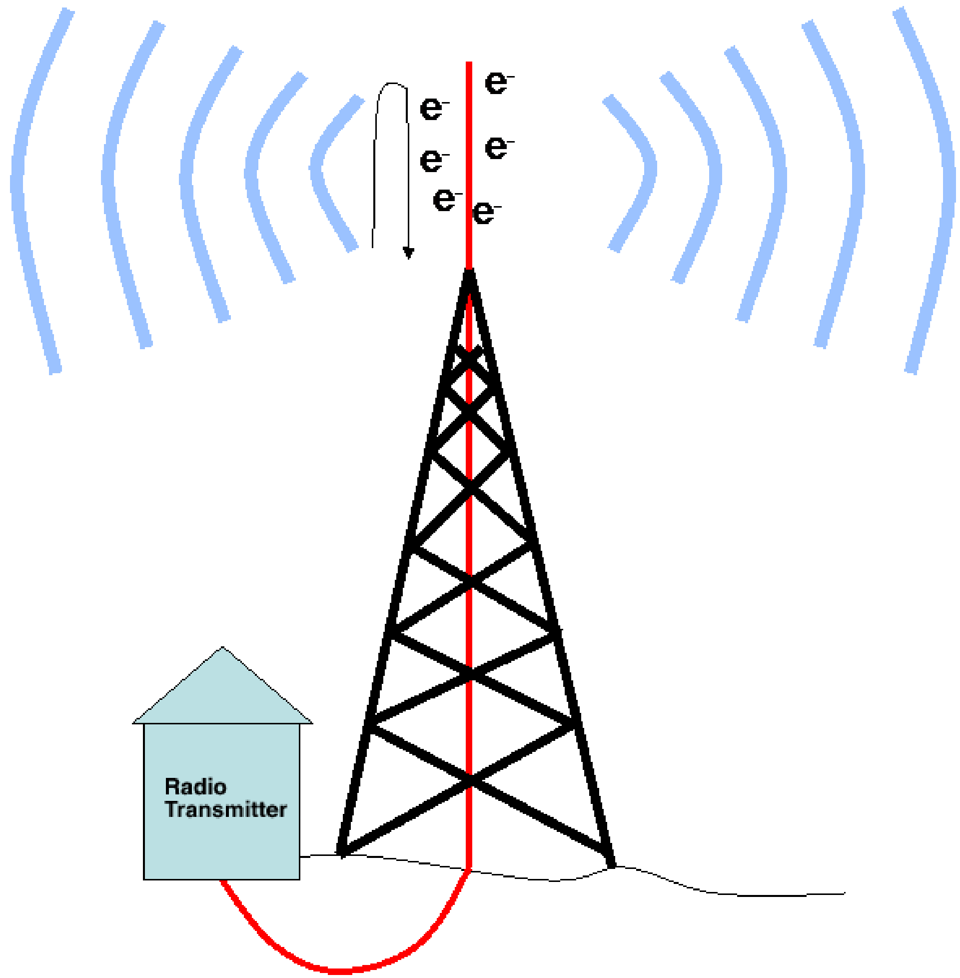
İÇERİK

- ✓ **Sinkrotron Işınımı ve Özellikleri**
- ✓ **Sinkrotron Depolama Halkası**
- ✓ **Sinkrotron Demet Hattı**
- ✓ **Sinkrotron Işınımının Kullanım Alanları**
- ✓ **Dünyadaki Sinkrotron Tesisleri**
- ✓ **DESY/PETRAIII Sinkrotronunda Gerçekleştirilen Deneysel Çalışmalardan Örnekler**

Elektromanyetik Radyasyon

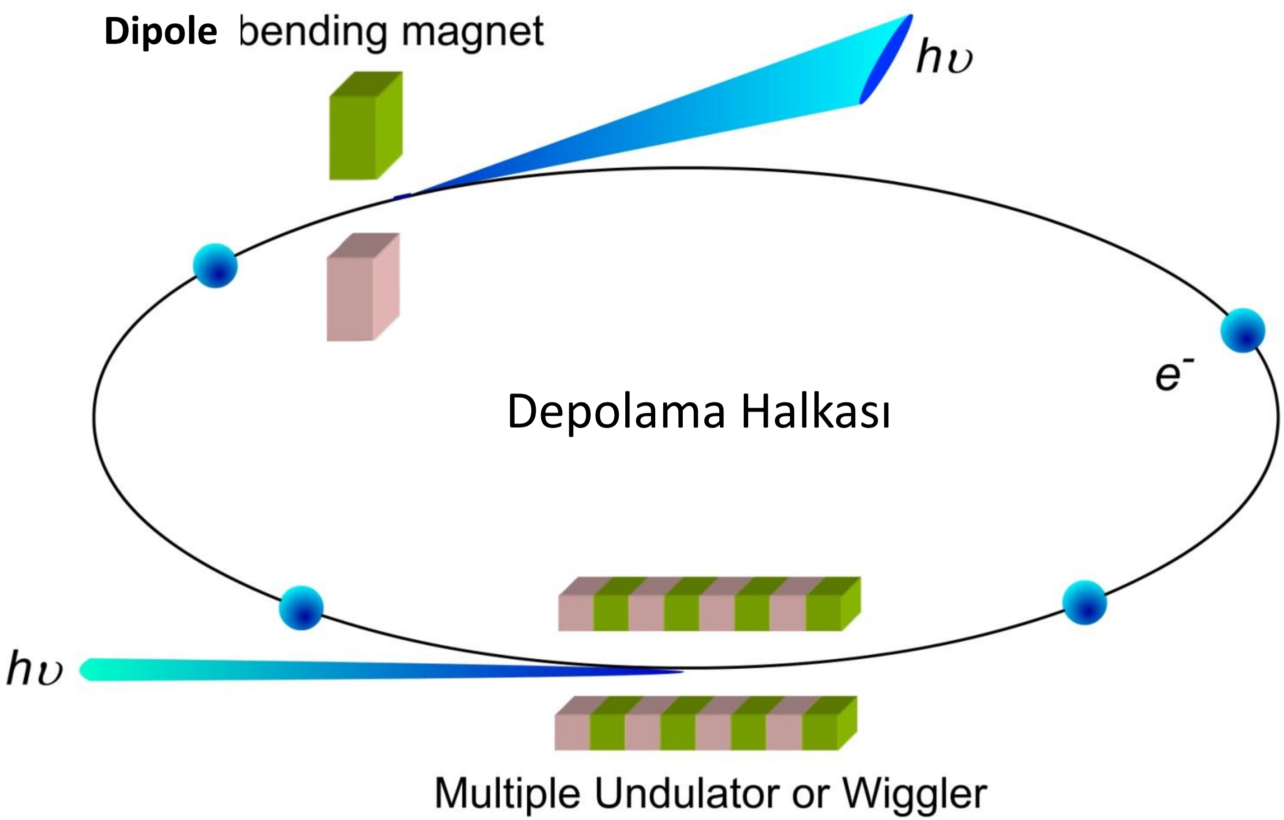
Bir radyo anteninde aşağı ve yukarı hızlandırılan elektronlar radyo dalgaları yayınlar





Sinkrotron Işınımı (SR) nedir?

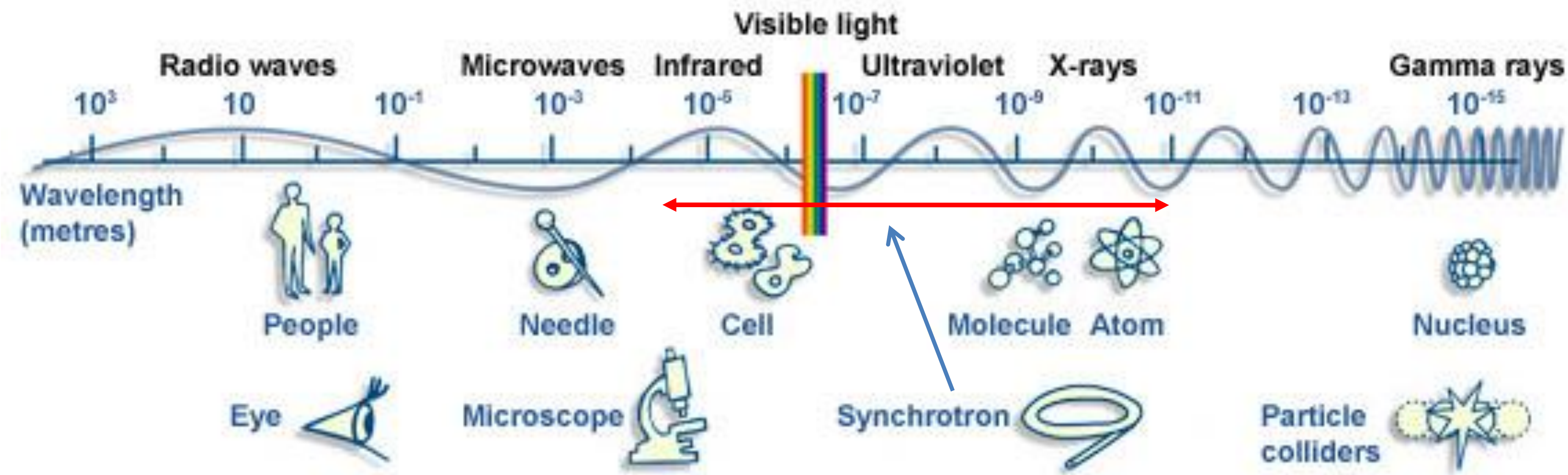
Rölativistik hızlarda (ışık hızına yakın hızlarda) hareket eden elektronlar yada diğer yüklü parçacıklar, periyodik manyetik alan içeren yapılardan geçmeye zorlandıklarında, hareket yönleri doğrultusunda elektromanyetik ışınım yayarlar.

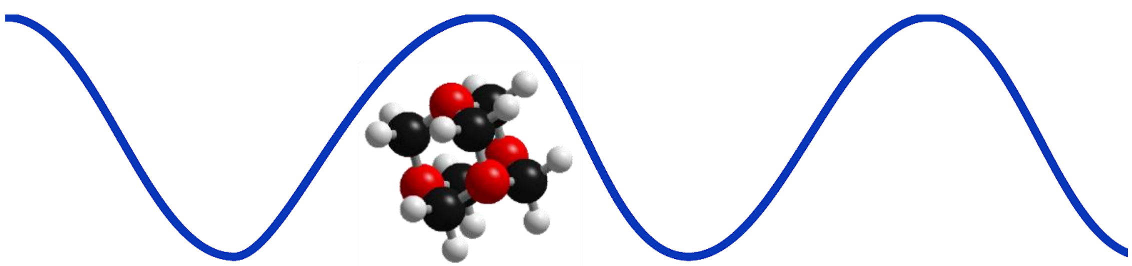


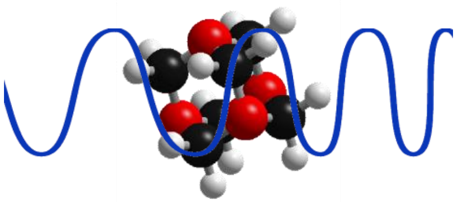
- Yüklü parçacıklar radyal olarak hızlandırılırlar ($v \perp a$)
- Manyetik alan, hareket yönlerine diktir

Sinkrotron Işınımının Özellikleri (I)

- Geniş spektral aralık



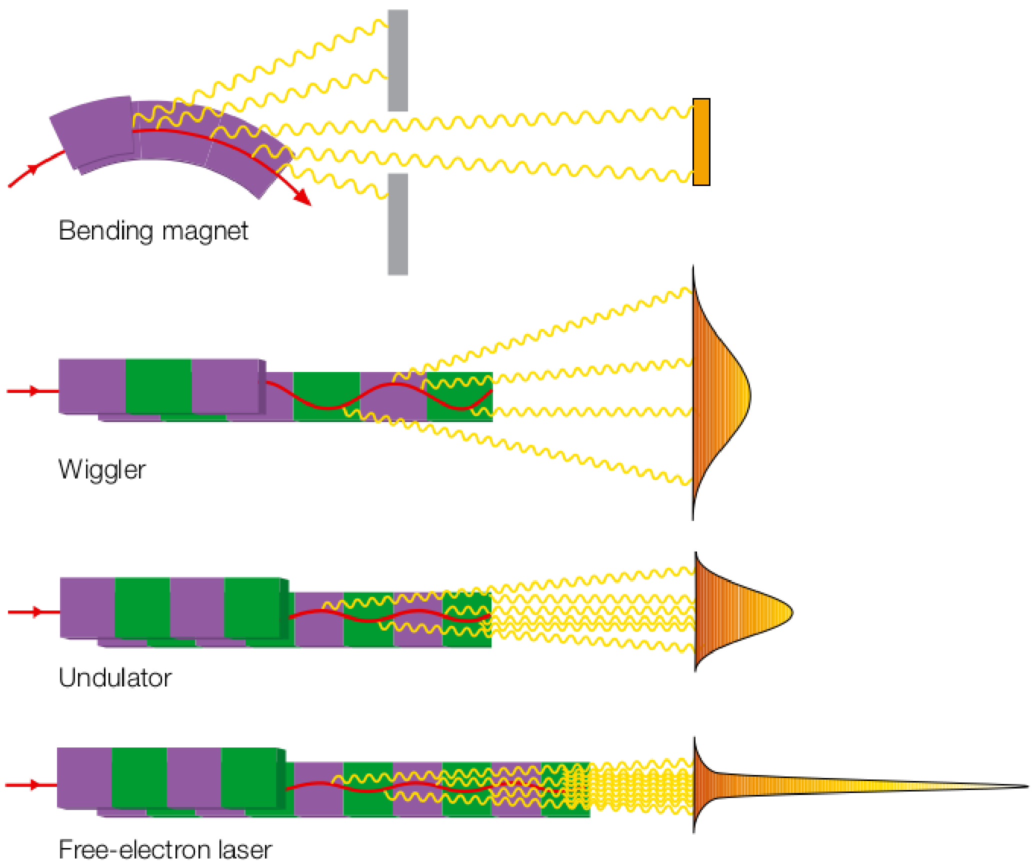


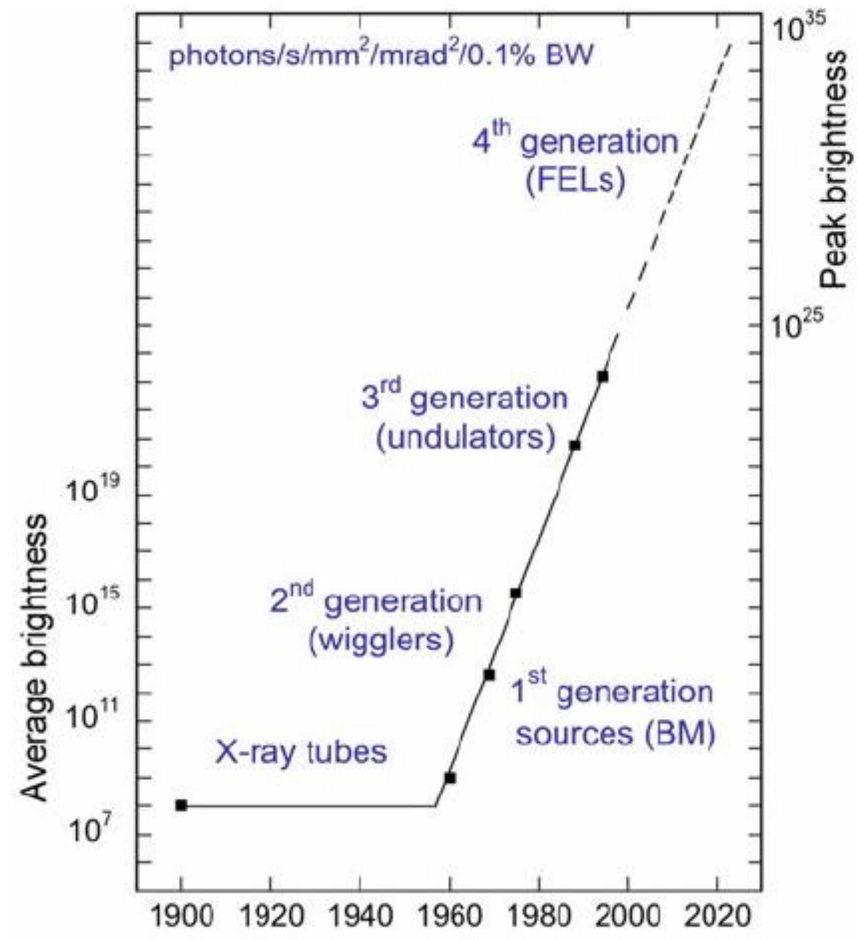


Sinkrotron Işınımının Özellikleri (II)

- **Yüksek Parlaklık**

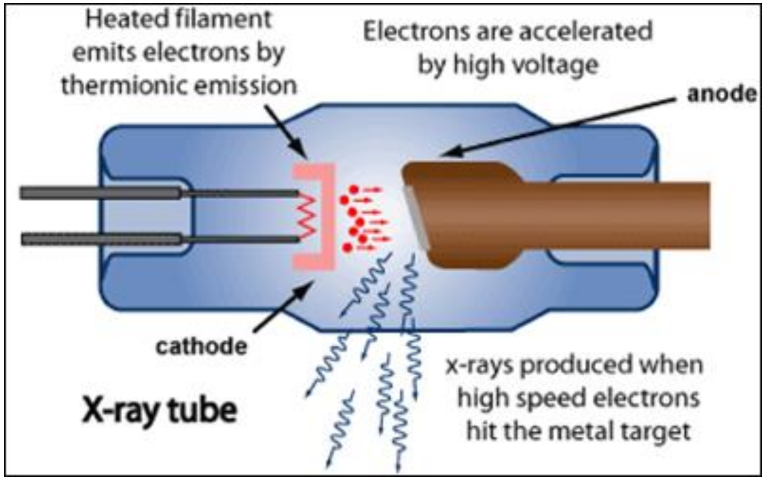
Parlaklık = Foton / (s · mm² · mrad² · 0.1% BW)

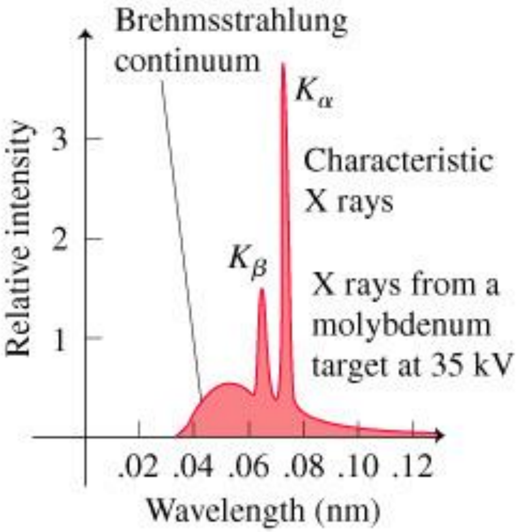


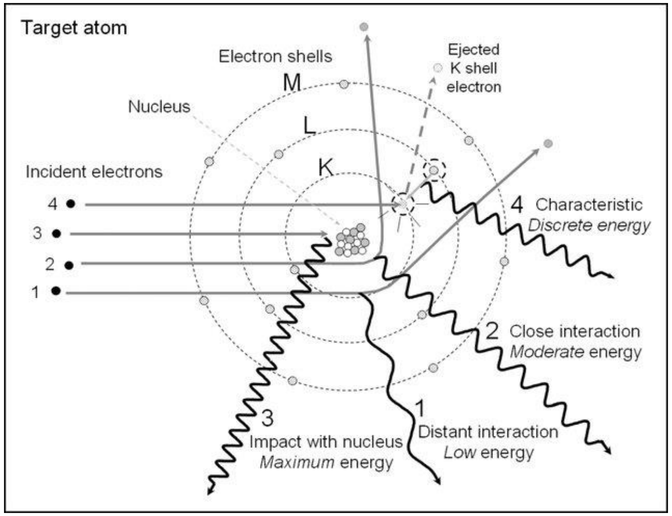


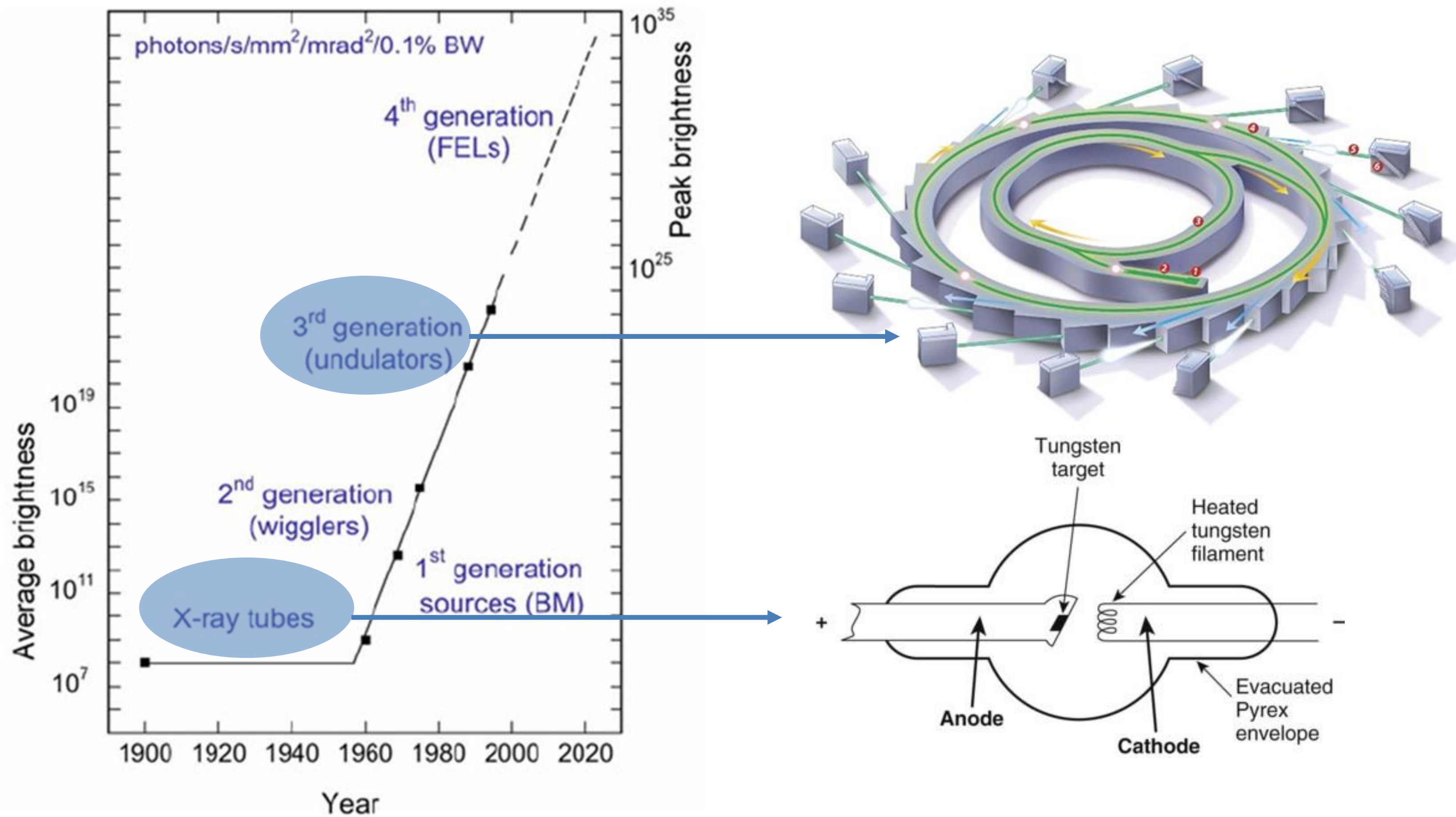
X-Işını Tüpü

- X-ışını parlaklığı sinkrotron ışınımına kıyasla oldukça düşüktür (~10^{10} kat)
- X-ışını enerjisi sürekli ve ayarlanabilir değildir
- X-ışınları her yönde yayılır





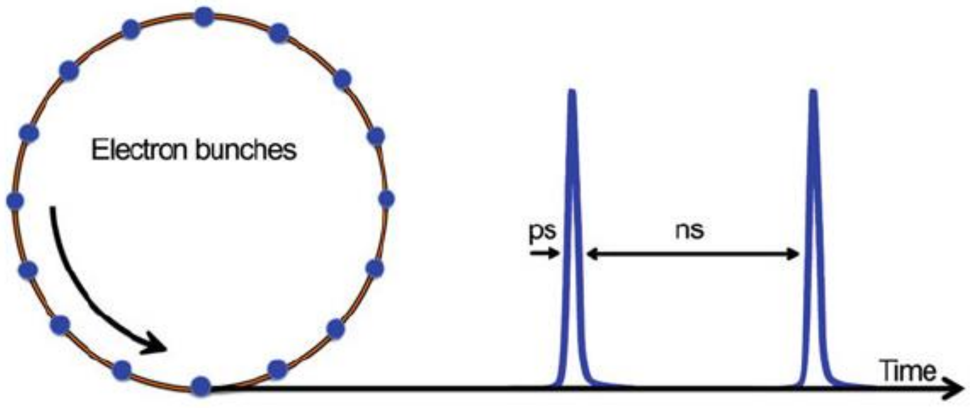




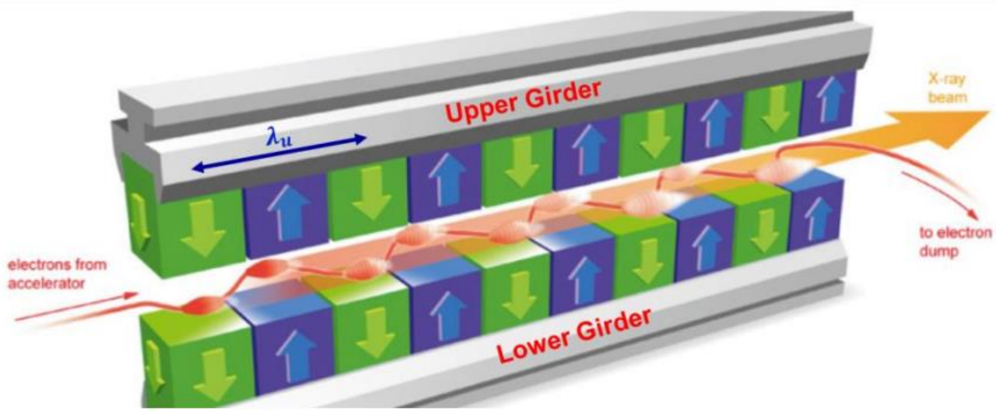
Hastanede kullanılan X-ışınlarından 100 milyar kat daha parlak !

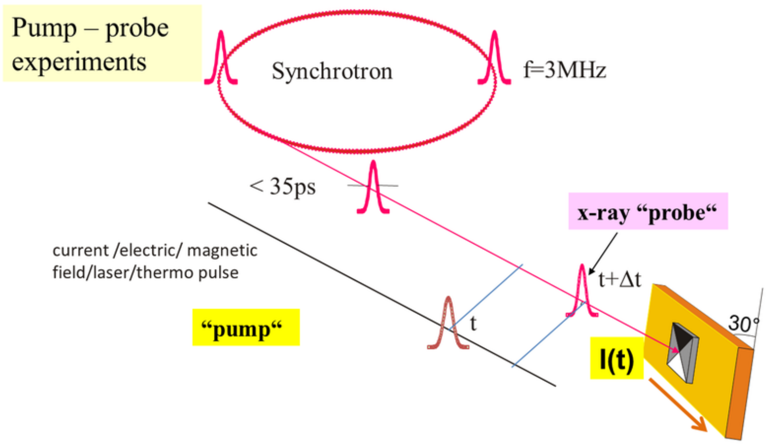
Sinkrotron Işınımının Özellikleri (III)

- **Atmalı zaman yapısı**



Electron bunches moving in the storage ring produce radiation peaks having the same bunch length (ps) and separation (ns)





Dairesel-Doğrusal Hızlandırıcı

Sinkrotron

FEL

Dairesel hızlandırıcılarda; parçacıklar dairesel yörüngeyi defalarca dolanır

Doğrusal hızlandırıcılarda; parçacıklar hızlandırıcı yapıdan sadece bir kez geçerler

Sinkrotronun Şematik Görünümü

2

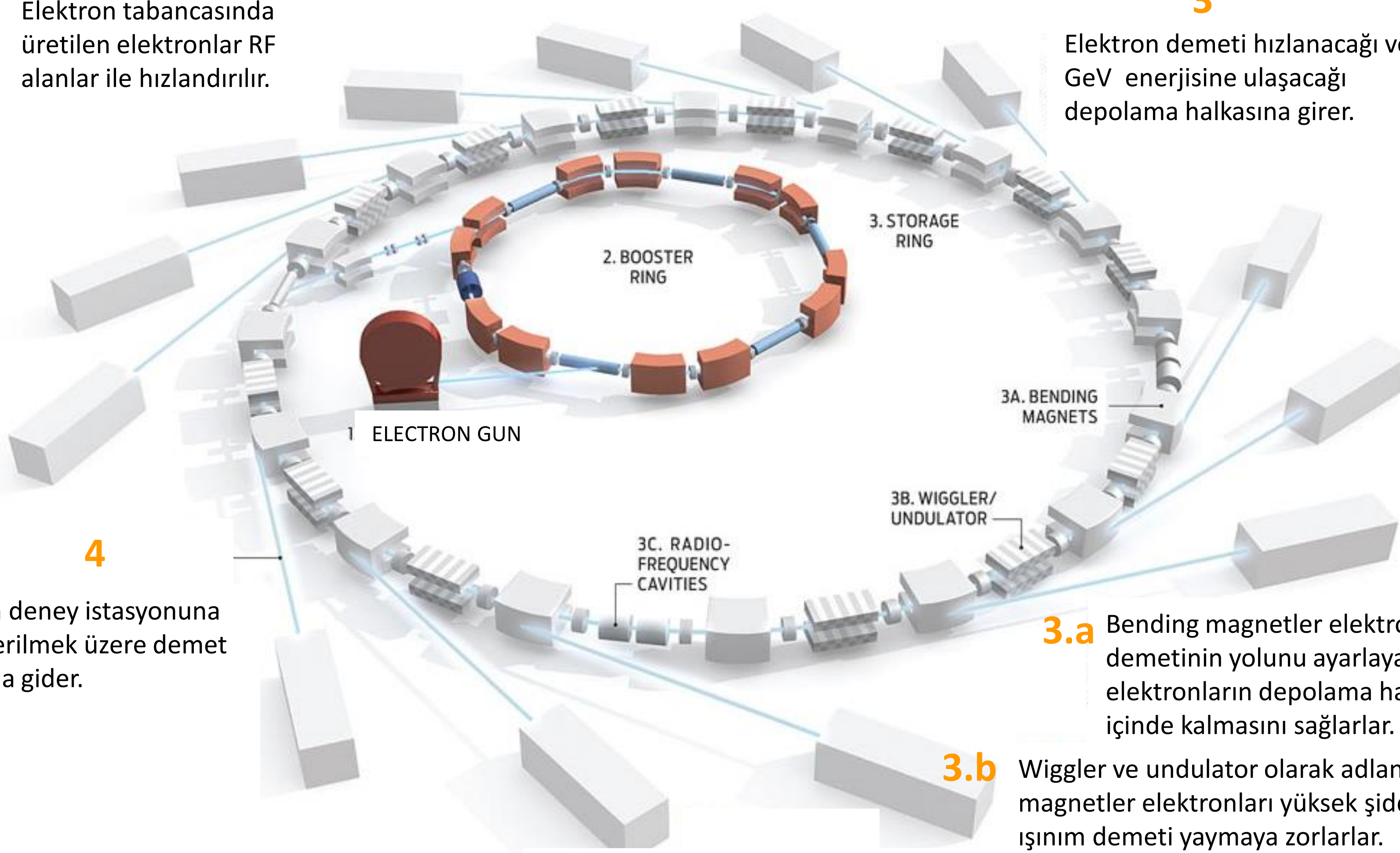
Elektronlar küçük halkaya girerler. Magnetler elektronların dairesel bir yol izlelemelerini, RF alanları da daha yüksek enerjilerde hızlandırılmasını sağlarlar.

1

Elektron tabancasında üretilen elektronlar RF alanlar ile hızlandırılır.

3

Elektron demeti hızlanacağı ve GeV enerjisine ulaşacağı depolama halkasına girer.



4

Işınım deney istasyonuna gönderilmek üzere demet hattına gider.

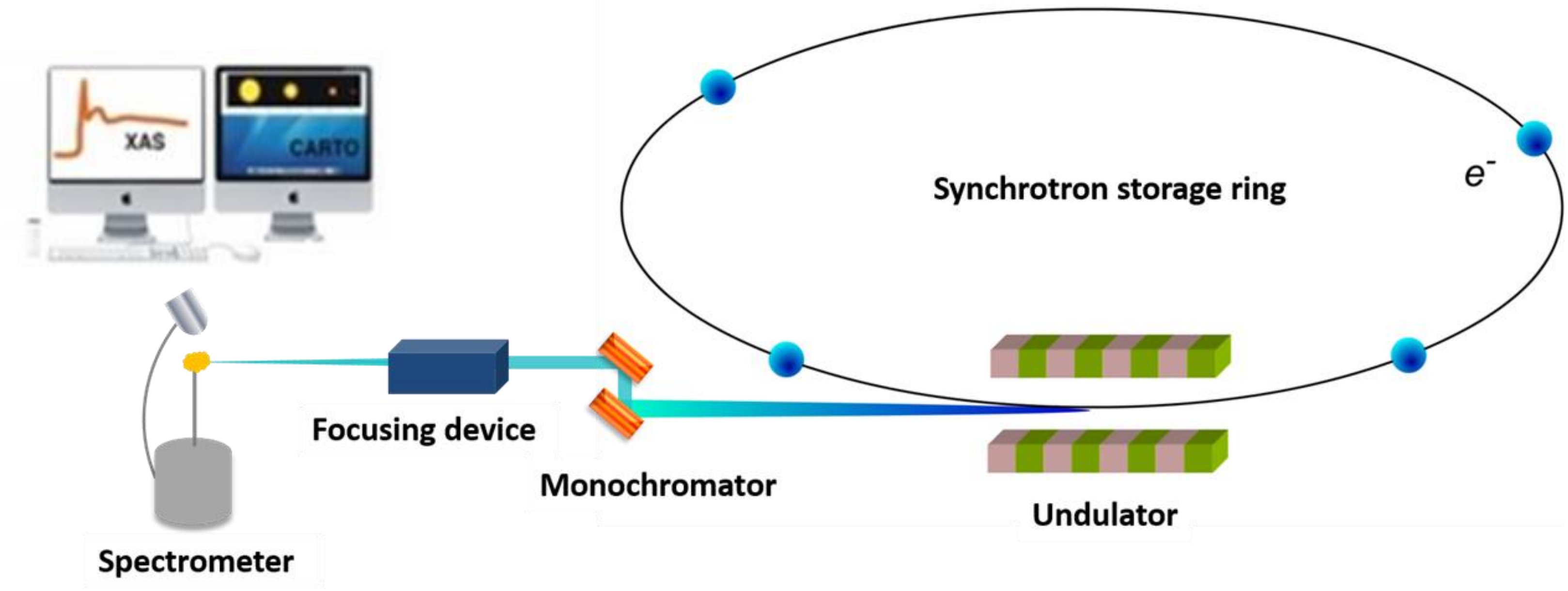
3.a Bending magnetler elektron demetinin yolunu ayarlayarak elektronların depolama halkası içinde kalmasını sağlarlar.

3.b Wiggler ve undulator olarak adlandırılan magnetler elektronları yüksek şiddette ışınım demeti yaymaya zorlarlar.

3.c RF kaviteler, elektronlara kaybettikleri enerjiyi geri kazandırırlar.

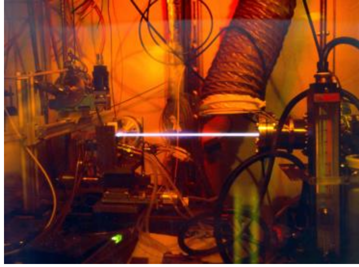
RF: RadyoFrekans

Well-collimated, highly monochromatic, focused beam is delivered onto sample



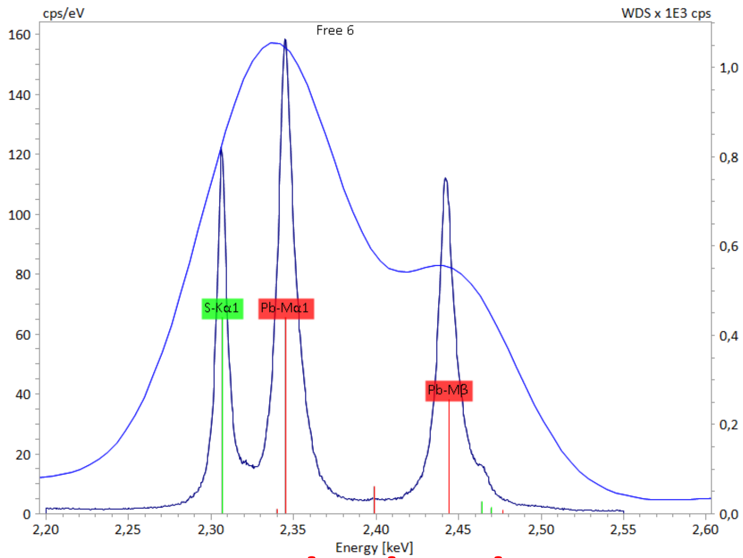
- Provide sample environment
- Interaction of synchrotron beam with sample
- Detector records data

Beam Characteristics

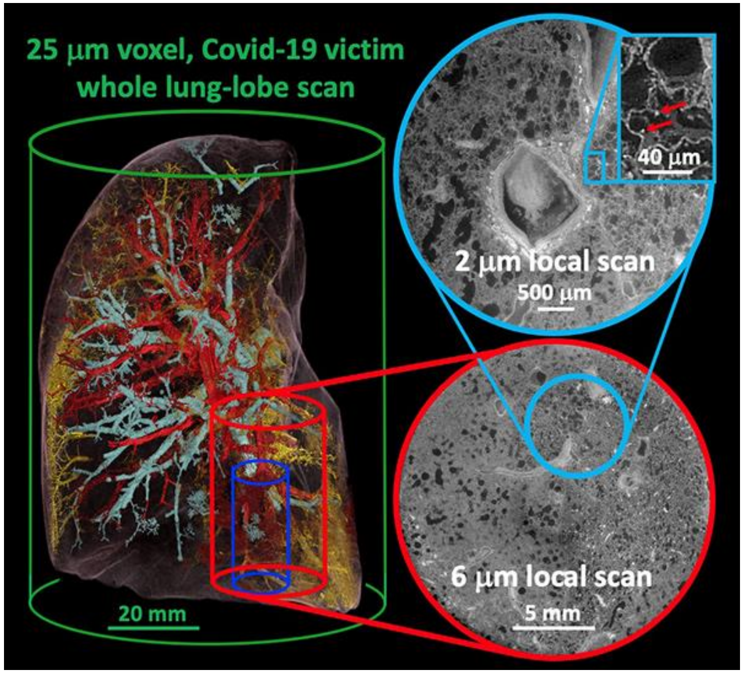


For synchrotron based user experiments, radiation characteristics such as **energy resolution, flux** and **beamsize** are of great importance in terms of the feasibility of the experiment

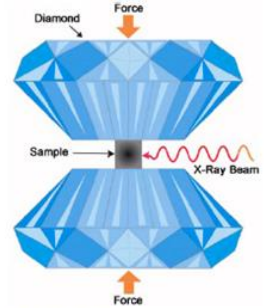
Resolving peaks in detail



Zooming down to cellular level



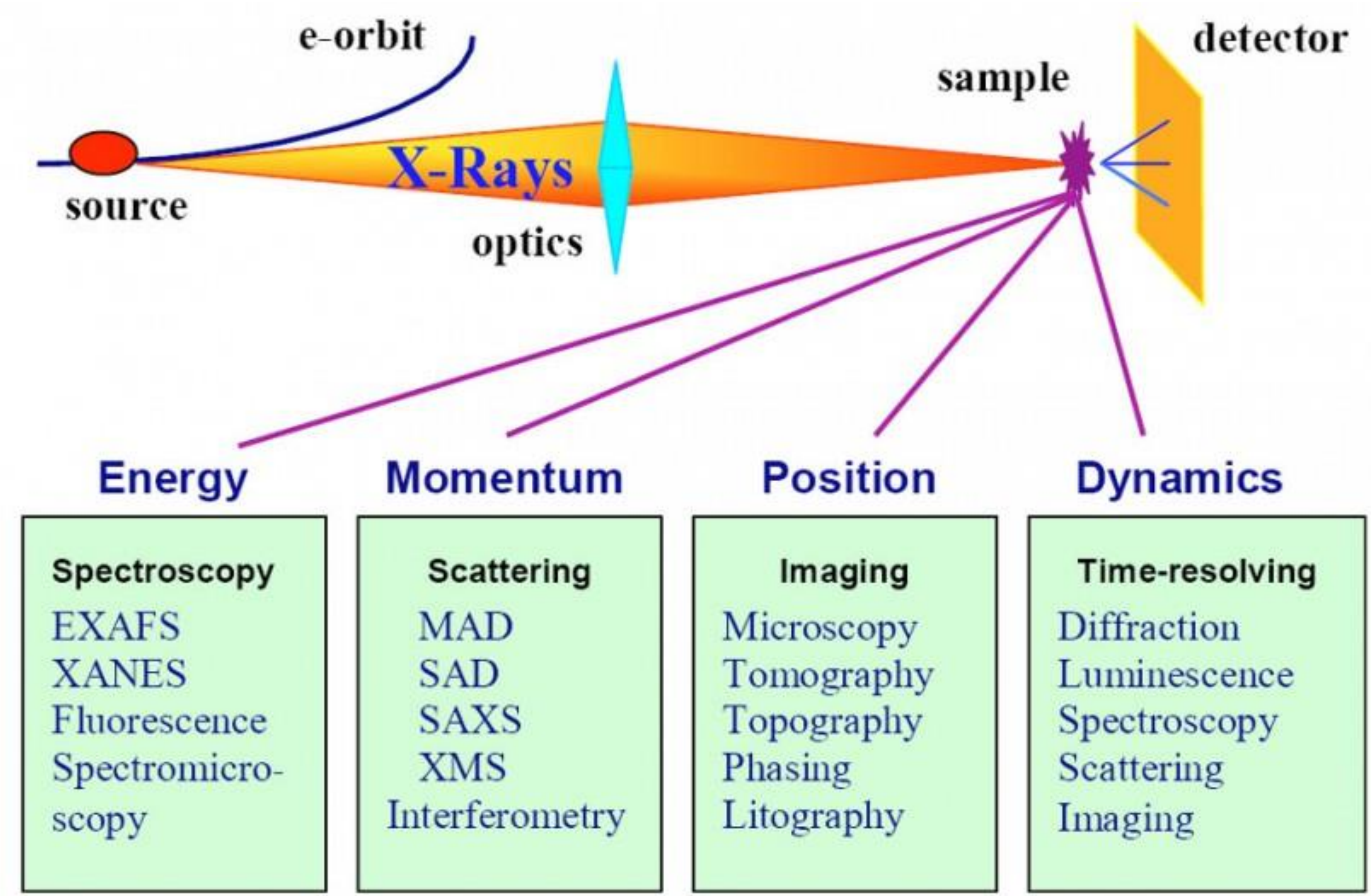
Beamsize in microns

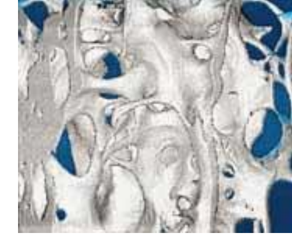


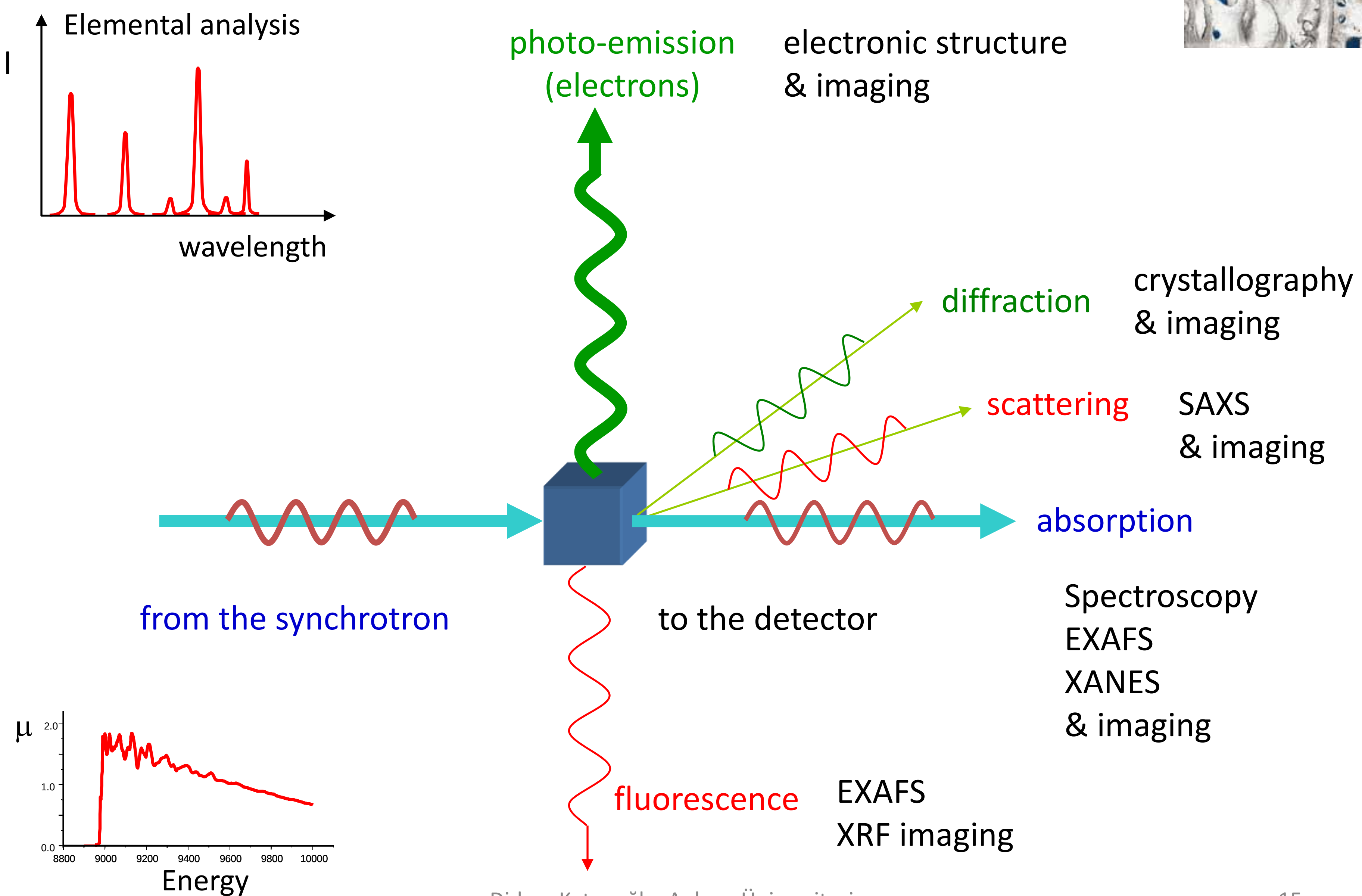
Diamond-anvil cell.

Due to this intense brilliance, researchers can view blood vessels five microns in diameter (a tenth of the diameter of a hair) in an intact human lung. A clinical CT scan only resolves blood vessels that are about 100 times larger, around 1mm in diameter. (ESRF,Grenoble)

Deneysel Teknikler

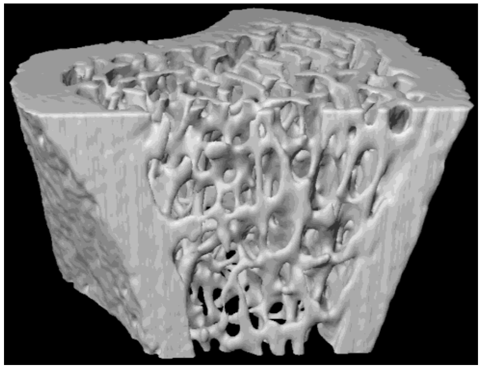




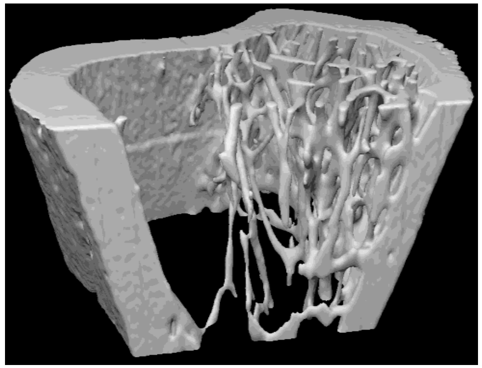


Elemental analysis
I
wavelength
photo-emission
(electrons)
electronic structure
& imaging
diffraction
crystallography
& imaging
scattering
SAXS
& imaging
absorption
from the synchrotron
to the detector
Spectroscopy
EXAFS
XANES
& imaging
μ
2.0
1.0
0.0
8800
9000
9200
9400
9600
9800
10000
Energy
fluorescence
EXAFS
XRF imaging

TIP

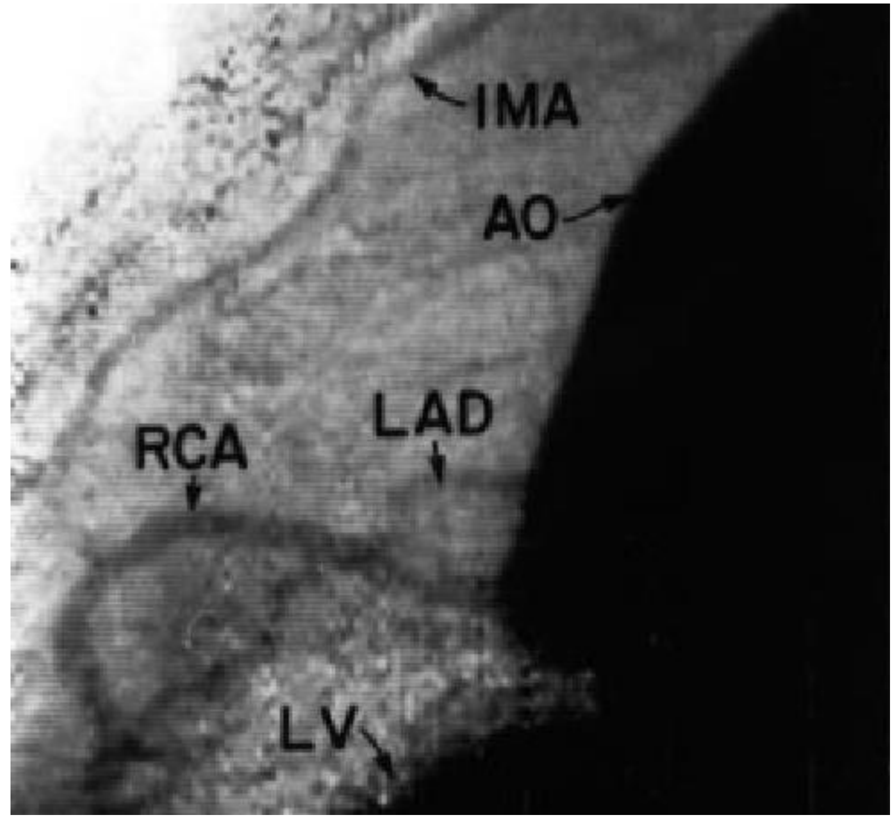


Östrojen kaybından önce



Östrojen kaybından sonra

Osteoporoz (kemik dokusunun içinde anormal derecede boşuk oluşumu)



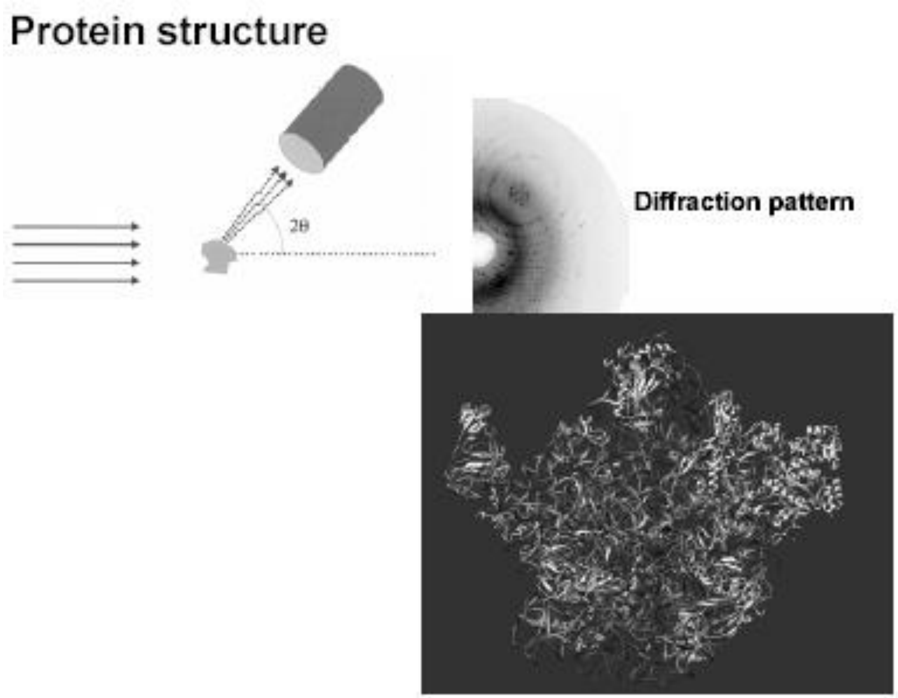
Koroner atardamarının sinkrotron ışınımı kullanılarak alınan görüntüsü (SSRL, 1986)

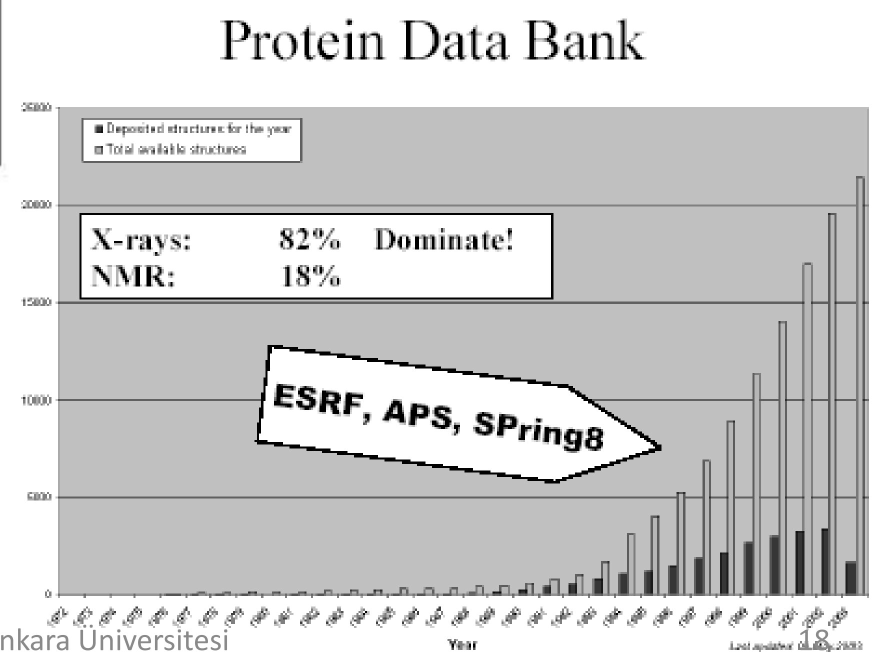
Hücresel Boyutta Görüntüleme

Sıtma mikrobu tarafından enfeksiyona uğramış kan hücresinin kan damarlarına tutunmasının nedeninin araştırılması

Sıtma mikrobunun etkilediği kan hücresinin X-ışını mikroskobu ile alınan görüntüsü (Berkeley Laboratuvarları)

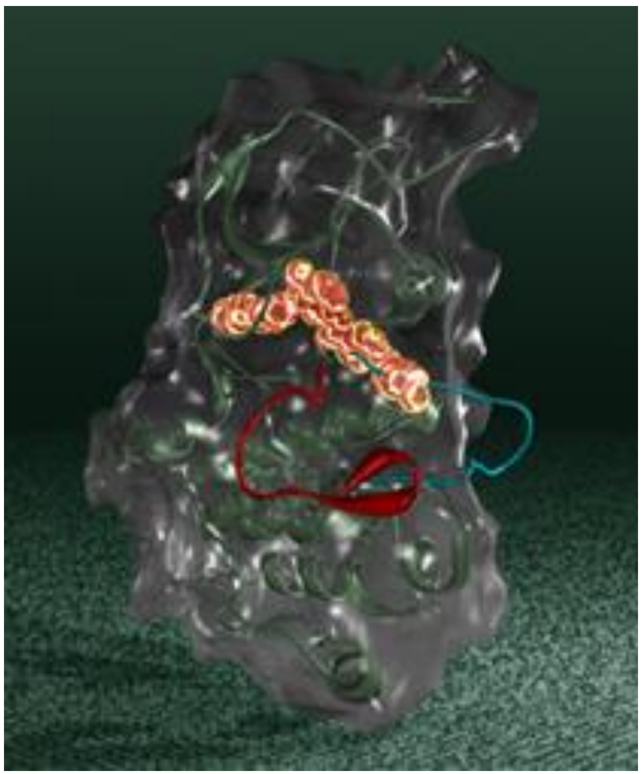
Protein Kristalografisi





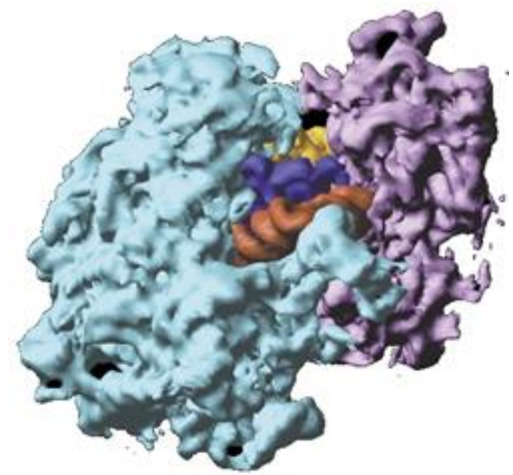
Genetik bozukluklar ile ilgili bilgiye sahip olmak ve bunların tedavisi için gerekli ilaçların üretiminde herbir proteinin detaylı yapısını araştırmamız gerekir

İlaç tasarımı
GLEEVEC

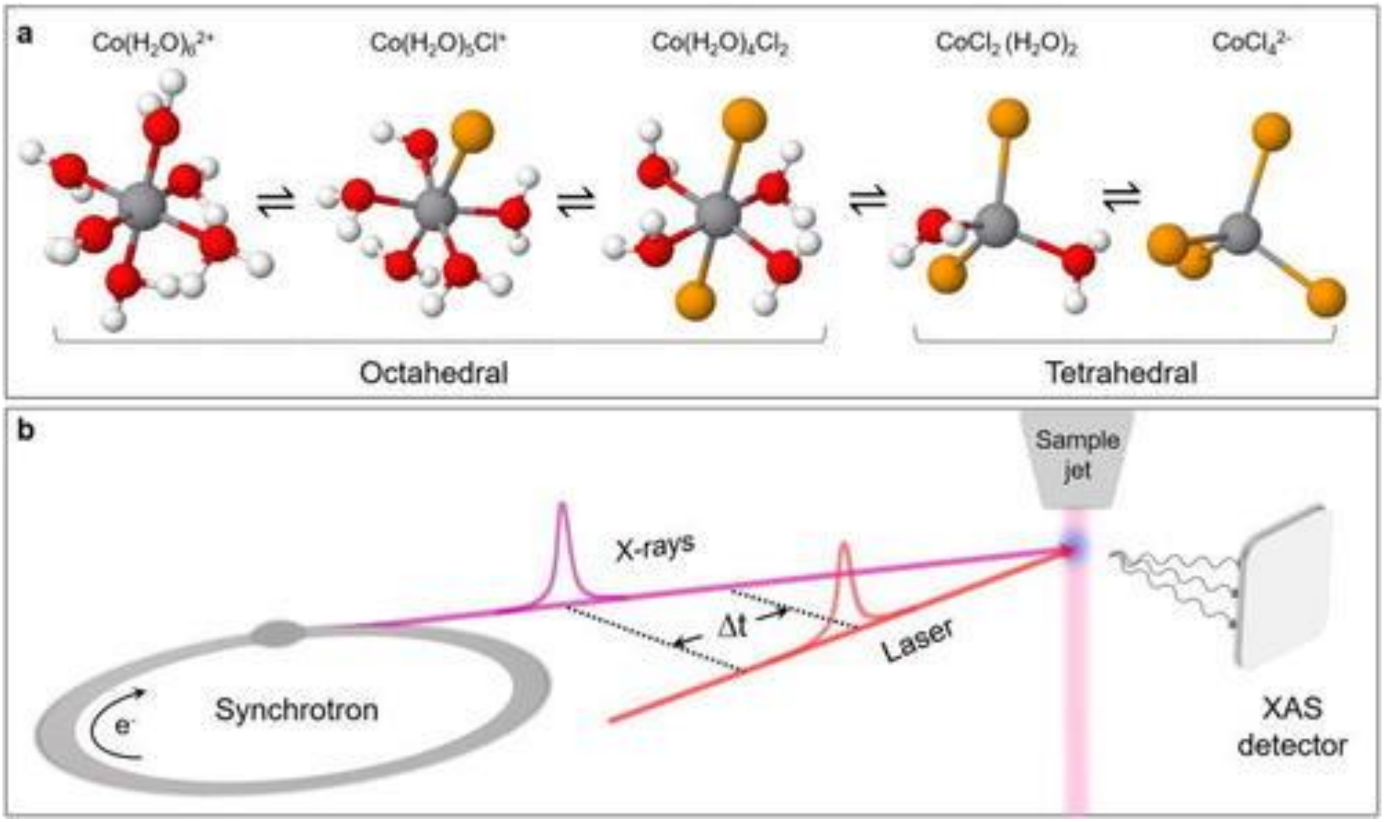


Lösemi

Proteinlerin nasıl oluştuğununun anlaşılması

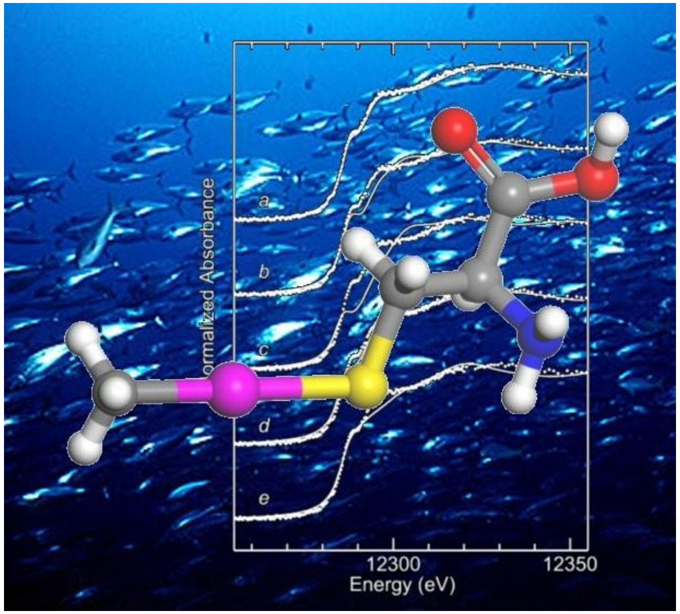


Moleküler yapıdaki değişimler: Pump-Probe deneyleri

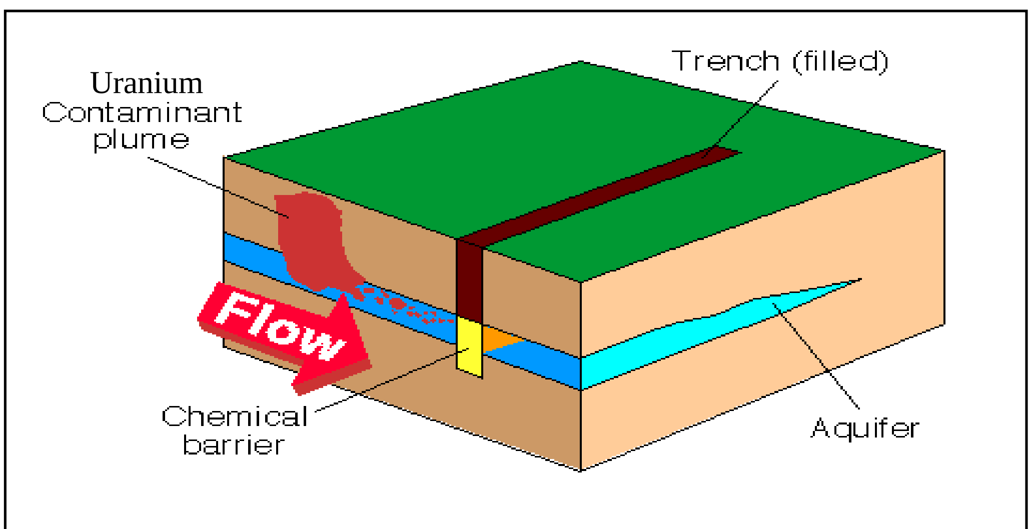


Pump: Laser
Probe: Synchrotron radiation

KİMYA & ÇEVRE BİLİMİ

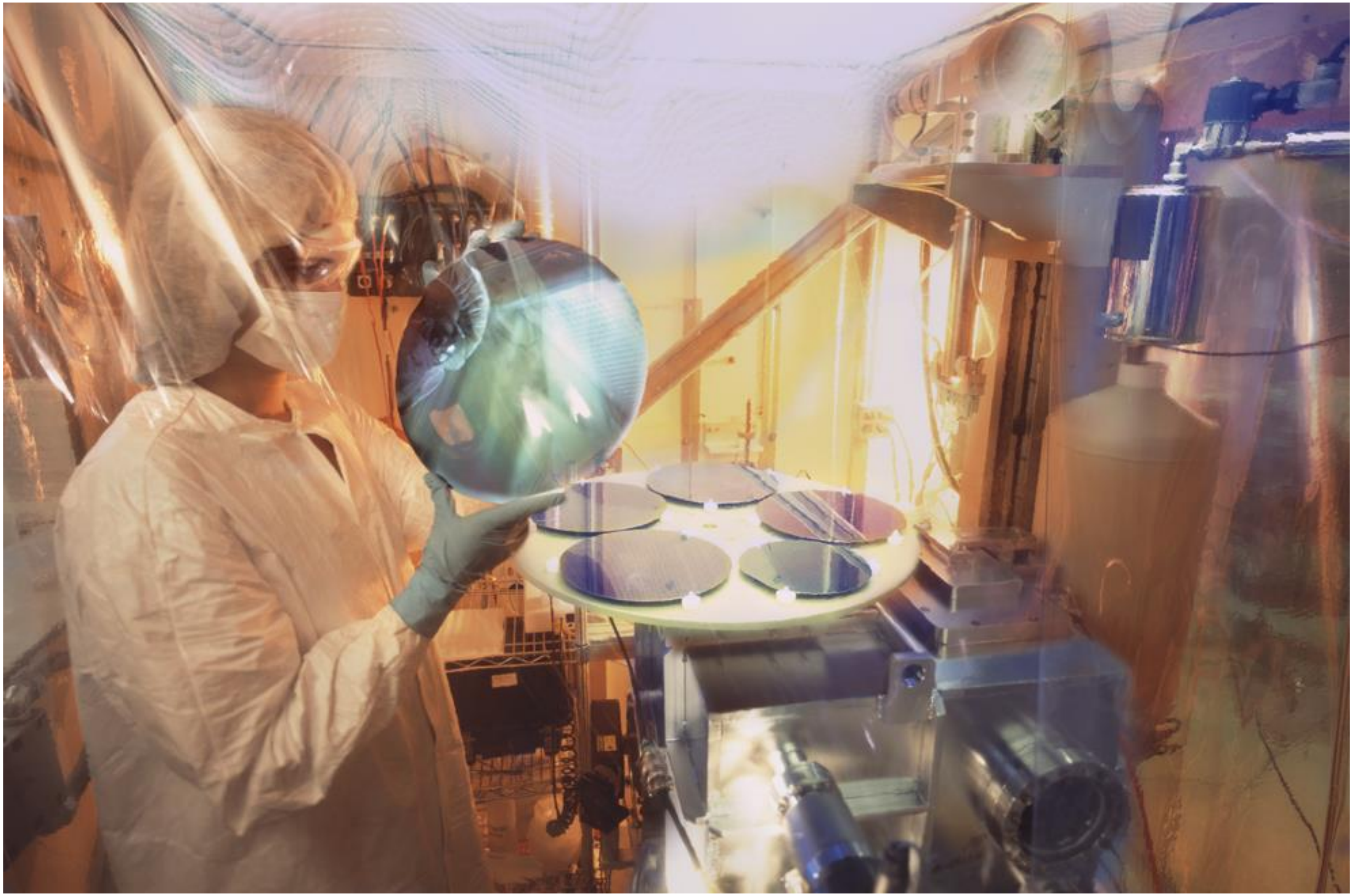


Balıkta bulunan çok düşük seviyedeki civanın ölçümü ve kimyasal formunun belirlenmesi

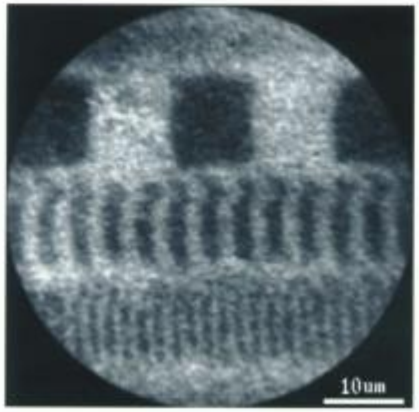


Su kaynaklarını tehdit eden toksik ve radyoaktif atıkların SR yolu ile anlaşılması (SSRL)

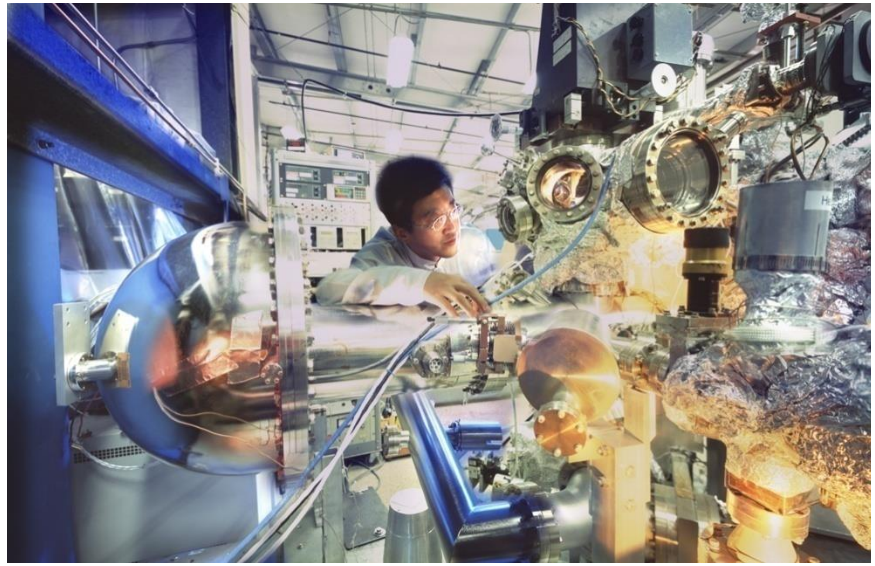
MALZEME BİLİMİ



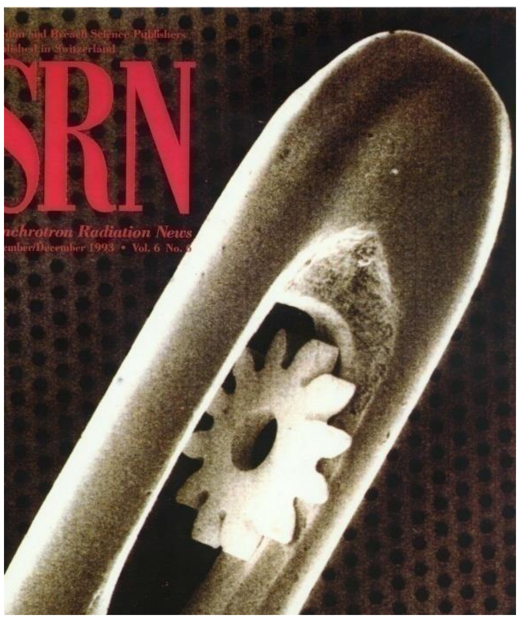
Bilgisayar çiplerinde sorunlara yol açan silikon yüzeylerdeki kirlenme seviyesinin SR kullanılarak incelenmesi



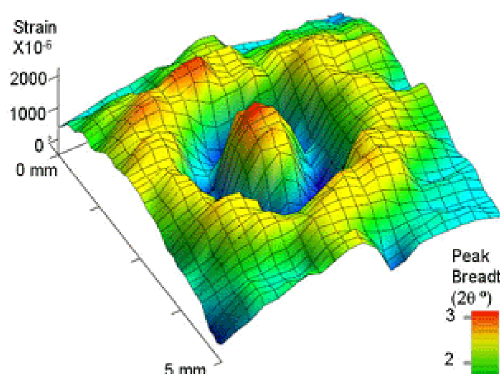
Bilgisayarın hard diskindeki magnetik çiplerin görüntülenmesi

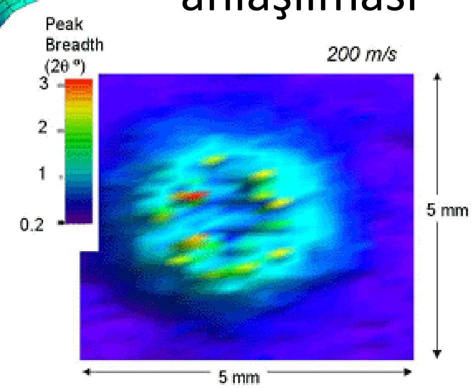


Yüksek sıcaklık süperiletkenlerinin nasıl çalıştığını anlamak için SR kullanımı



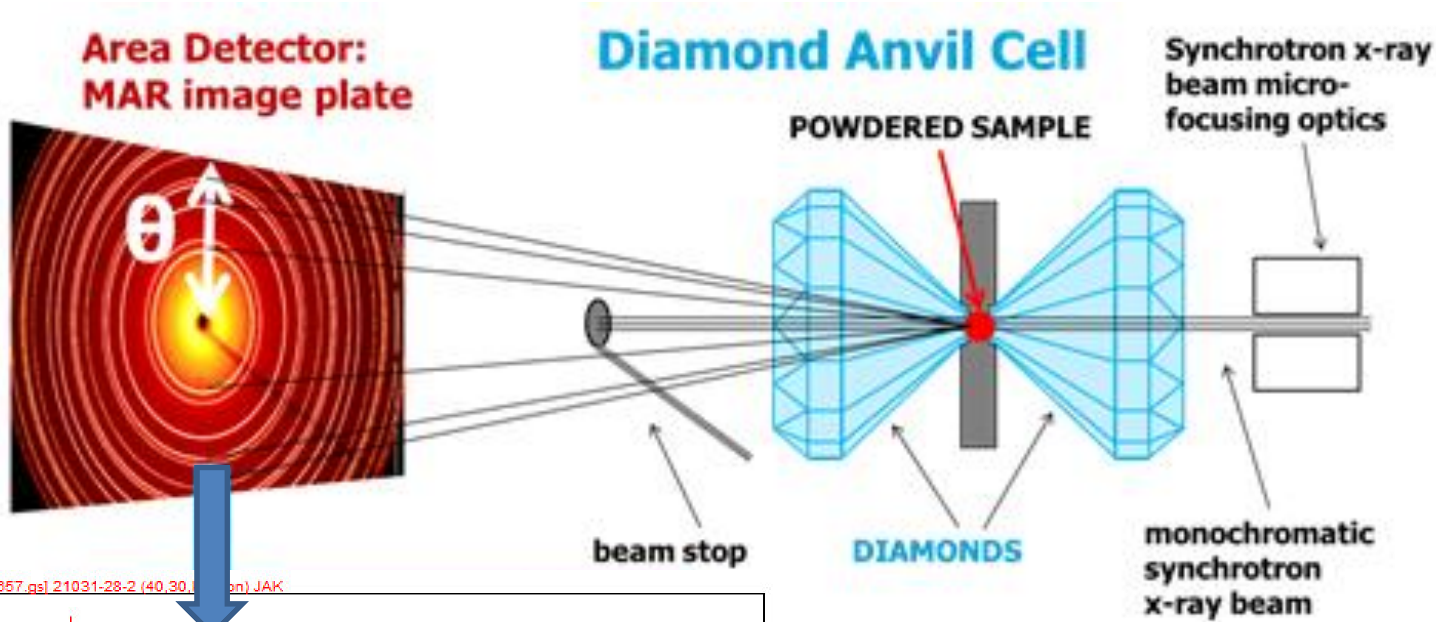
SR kullanarak minyatür mekanik ve elektromekanik aygıtların yapımı

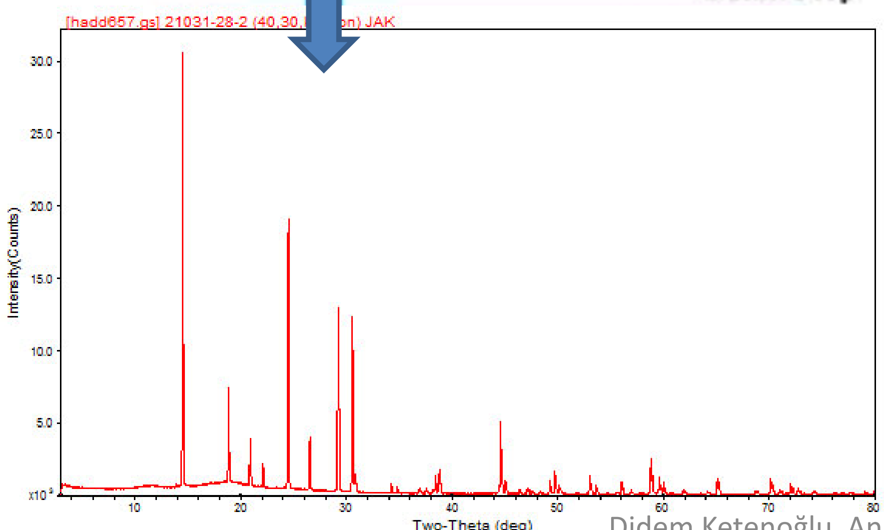




Uçak türbinlerine yabancı maddelerin nasıl zarar verdiğinin SR yolu ile anlaşılması

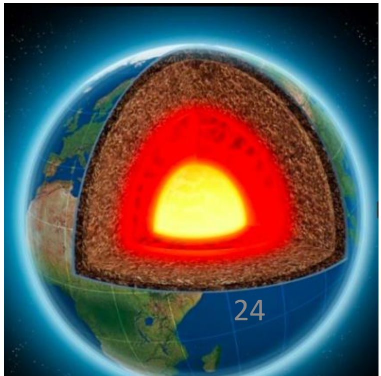
JEOLOJİ BİLİMİ





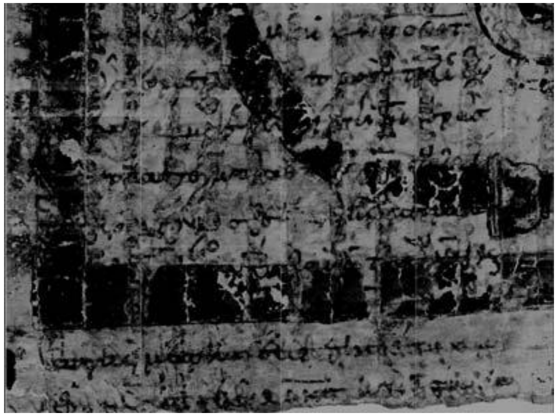
The Bragg Equation

$$n\lambda = 2d\ sin\theta$$



SANAT & ARKEOLOJİ

SSRL merkezinde bulunan sinkrotron X-ışını demeti silinmiş, üzerine yazı yazılmış ve hatta üzerine resim yapılmış bir yazıyı ortaya çıkardı



X-ışını floresans görüntüleme yöntemi ile 10.yüzyıldan kalma yazılardaki demir içeren mürekkep incelenerek gizli kalmış bir yazı ortaya çıkarıldı

IMAGING APPLICATIONS IN PALAEONTOLOGY

"The many very advanced features found in the brain and body ...make it possibly the best candidate ancestor for our genus, the genus Homo."

Lee Berger, Wits U, Johannesburg

K.J. Carlson et al.; Science (2011)

Dünyadaki Sinkrotron Tesisleri

Image Source: http://www.veqter.co.uk/residual-stress-measurement/synchrotron-diffraction

- ✓ Amerika: 9
- ✓ Asya: 15
- ✓ Avustralya: 1
- ✓ Avrupa: 18

http://www.lightsources.org/regions

Synchrotron Radiation Facilities Around the World

Facility	Country	Energy (GeV)	Circumference (m)	Start of user operation
ASTRID	Denmark	0.58	40	1991
ESRF	France	6	844	1992
ELETTRA	Italy	2-2.4	260	1993
ALS, Advanced Light Source	US	1.9	196.8	1993
APS, Advanced Photon Source	US	7	1104	1995
Spring-8	Japan	8	1436	1997
ANKA, Karlsruhe Institute of Technology	Germany	2.5	110.4	2000
Swiss Light Source, Paul Scherrer Institute	Switzerland	2.8	288	2001
SLRI, Synchrotron Light Research Institute	Thailand	1.2	81.4	2004
Canadian Light Source	Canada	2.9	147	2004
Indus 2	India	2.5	173	2005
Diamond Light Source	UK	3	561.6	2006
SOLEIL	France	3	354	2006
Australian Synchrotron	Australia	3	216	2006
SSRF, Shanghai Synchrotron Radiation Facility	China	3.5	432	2007
MAX-III	Sweden	0.7	36	2008
PETRA-III, DESY	Germany	6	2304	2009
ALBA	Spain	3	270	2010
TPS, Taiwan Photon Source	Taiwan	3	518.4	2015
NSLS-II, National Synchrotron Light Source	US	3	792	2015

28

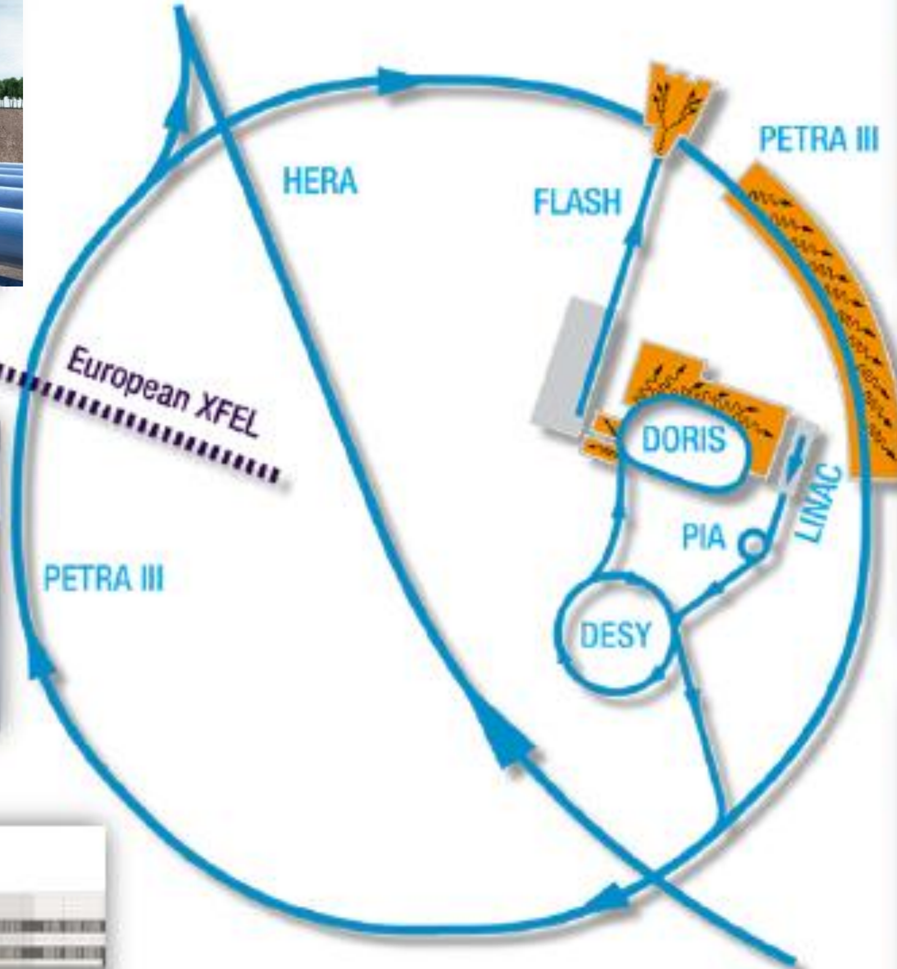
APS 7 GeV

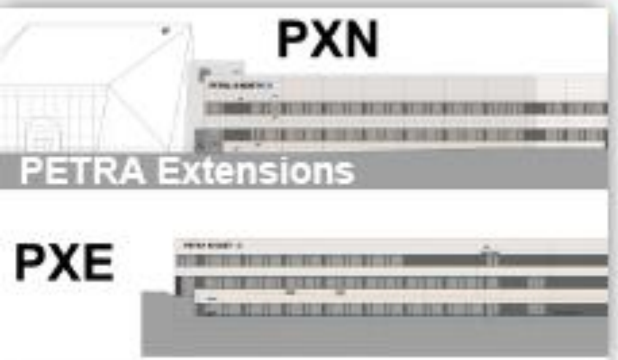
ESRF 6 GeV

Spring-8 8 GeV

PETRA-III 6 GeV

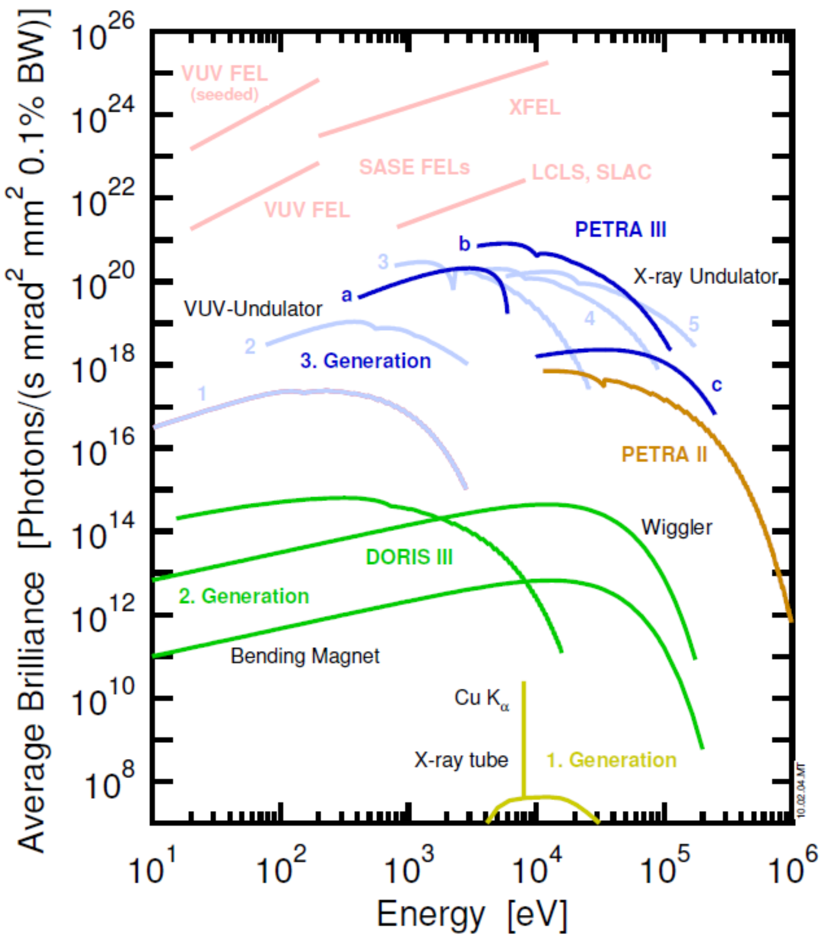
DESY FOTON KAYNAKLARI





PETRA III

Dünyanın en parlak sinkrotron ışınım kaynağı



Elektron enerjisi: 6 GeV
Parlaklık: 10^{21} foton/(s mm^{2}mrad^2 0.1% BW)
Sağlanan enerji aralığı: 50 eV–150 keV
Elektron demet akımı: 100 mA
Demet hattı: 19
Çevre : 2304 m
Kuruluş: 1978

DEMET HATLARI

P01 High Resolution Dynamics Beamline

P02 Hard X-Ray Diffraction Beamline

P03 MINAXS

P04 XUV Beamline

P05 Imaging Beamline

P06 Hard X-Ray Micro Probe

P07 High Energy Materials Science

P08 High Resolution Diffraction

P09 Resonant Scattering and Diffraction

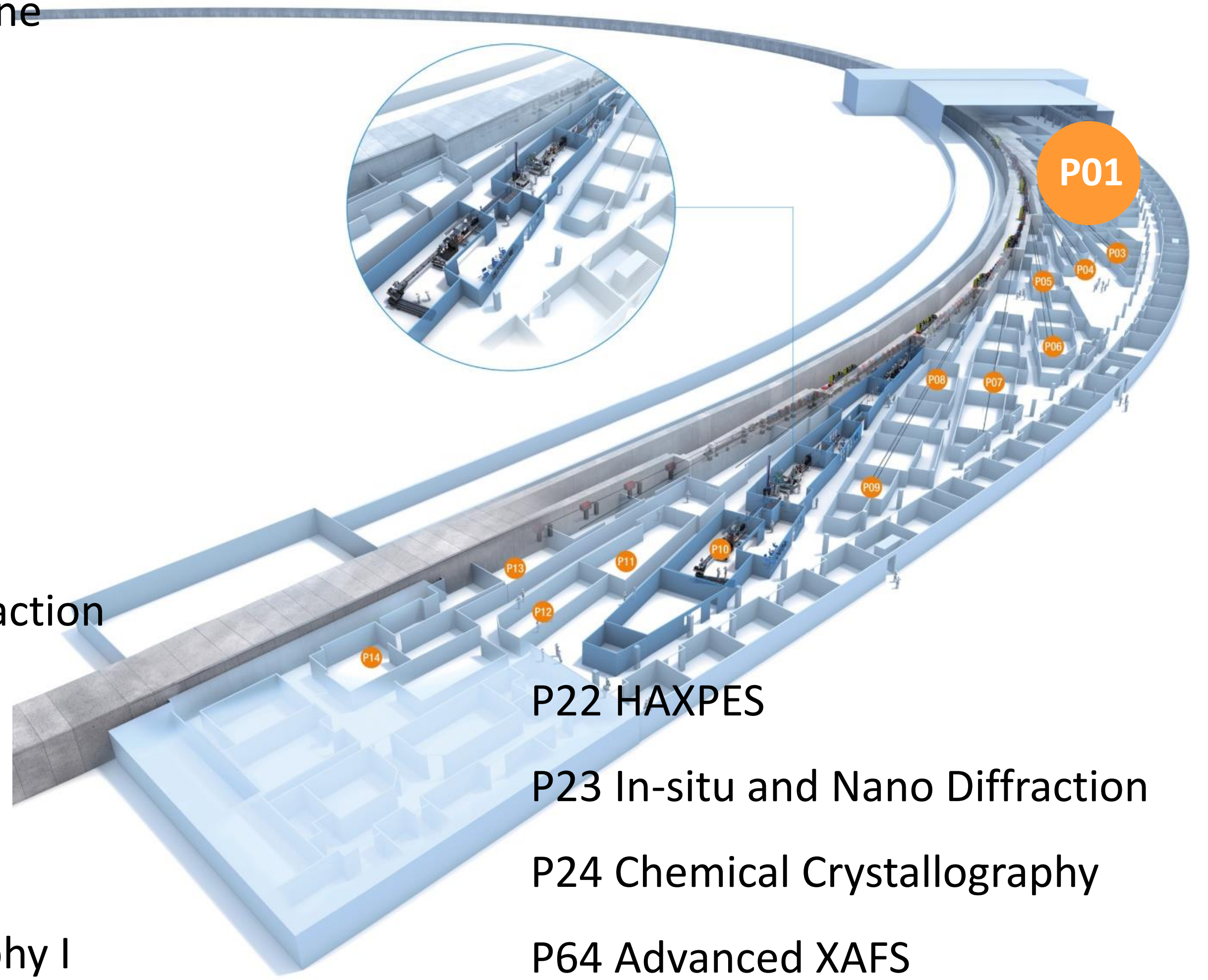
P10 Coherence Applications

P11 Bio-Imaging and Diffraction

P12 BioSAXS

P13 Macromolecular Crystallography I

P14 Macromolecular Crystallography II



P22 HAXPES

P23 In-situ and Nano Diffraction

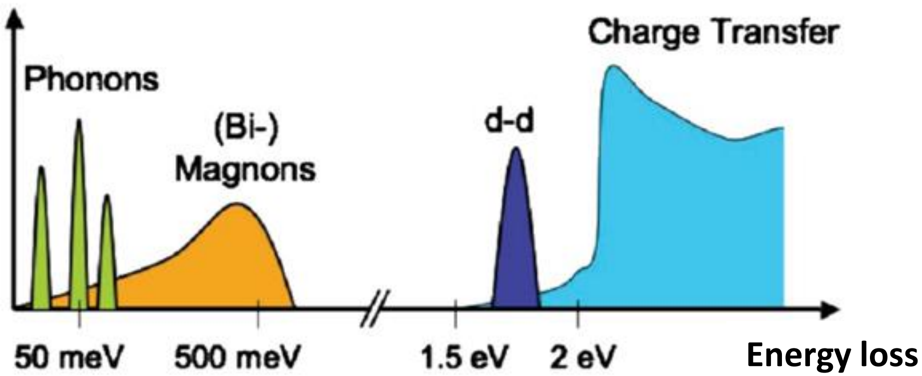
P24 Chemical Crystallography

P64 Advanced XAFS

P65 Applied XAFS

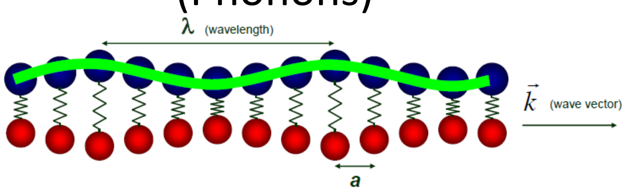
RIXS: Düşük Enerjili Uyarılmaların Ölçümü

Düşük enerjili uyarılmaların momentum transferine bağlı ölçümü



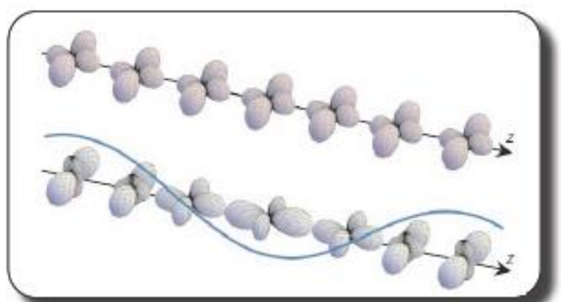
Elementary excitation spectrum

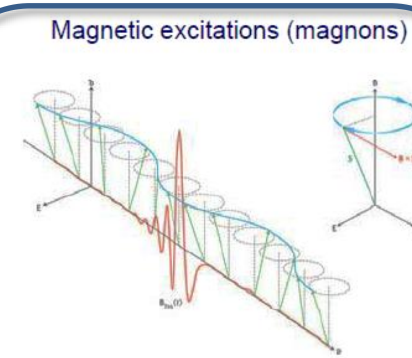
Lattice vibrations
(Phonons)



collective excitation of atoms or molecules in a crystal structure

Orbitons

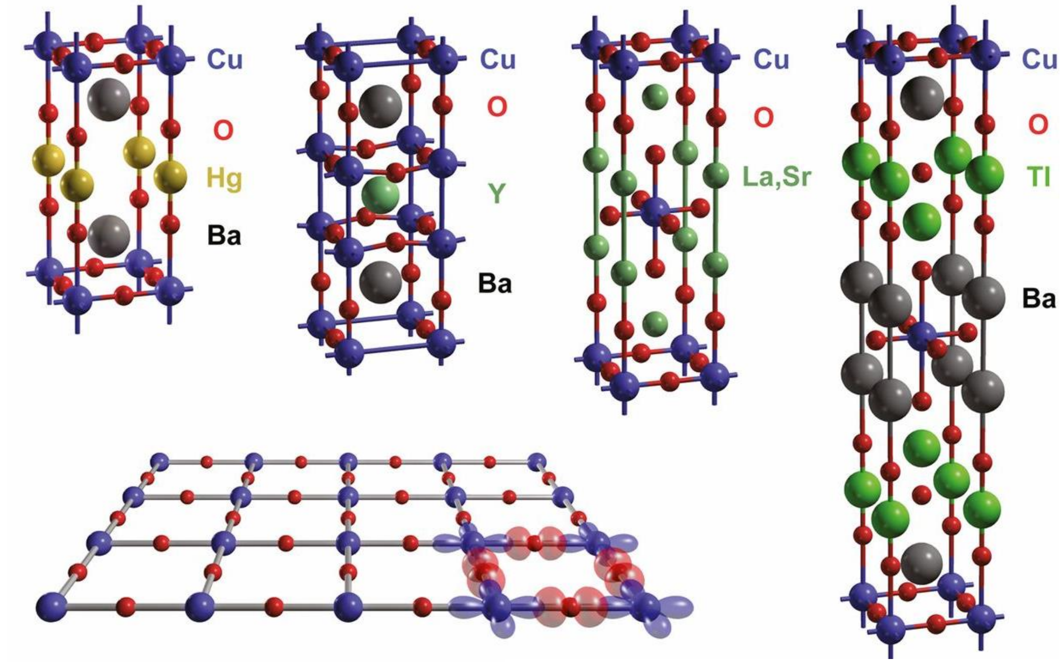


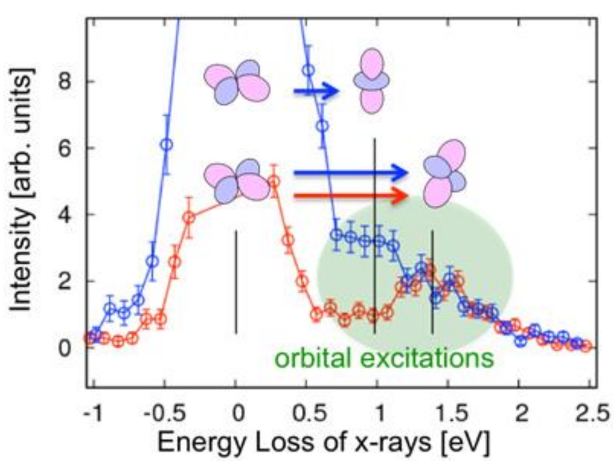


collective excitation of the electron’s spin structure in a crystal structure

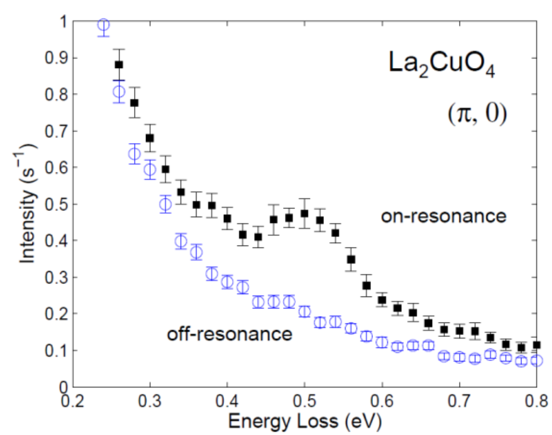
L. Ament et al., Resonant inelastic x-ray scattering studies of elementary excitations, Rev. Mod. Phys., ***83*** *(2011) 705-767*

Yüksek T_c Süperiletkenleri

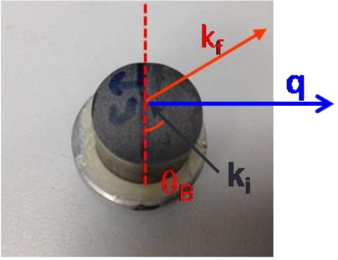




Two-magnon excitations in Cu K-RIXS



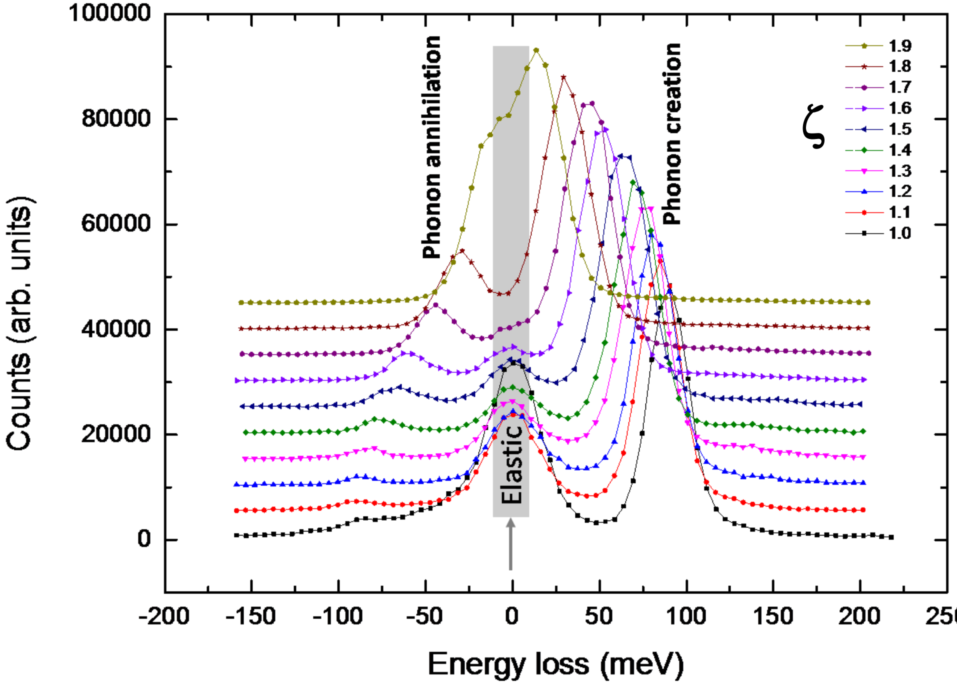
J. Hill et al., Phys. Rev. Lett. (2008).

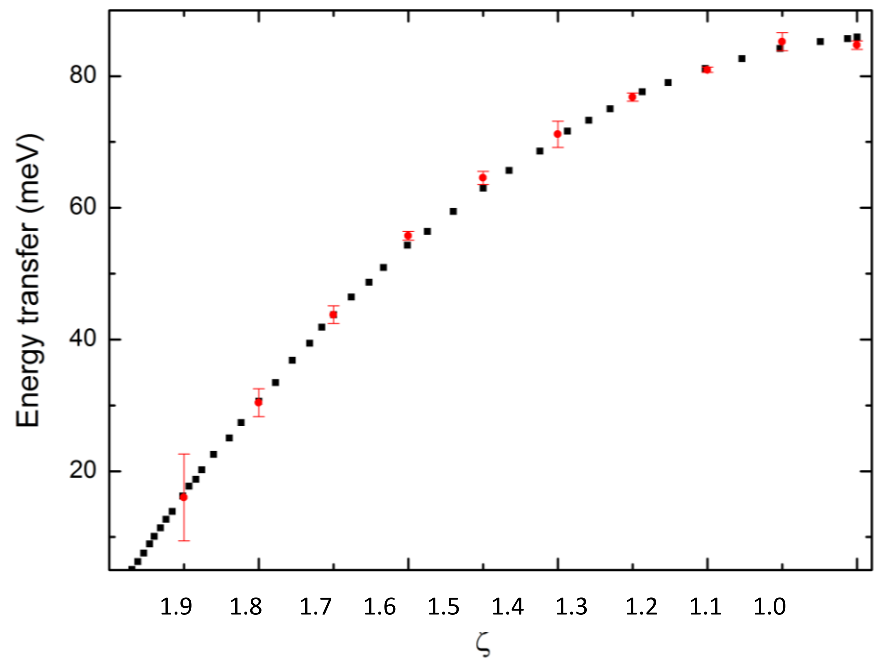


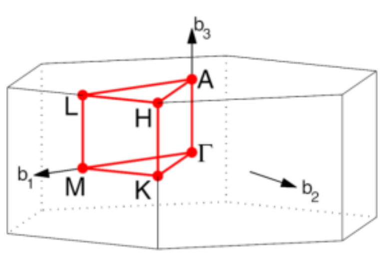
D.Ketenoglu et al., J. Synchrotron Rad. 22 (2015) 961-967

Berilyum tek kristalinde [00ζ] yönü boyunca fonon uyarılmaları

Data kaydetme süresi: 300 s

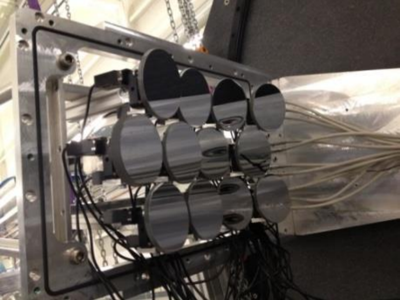


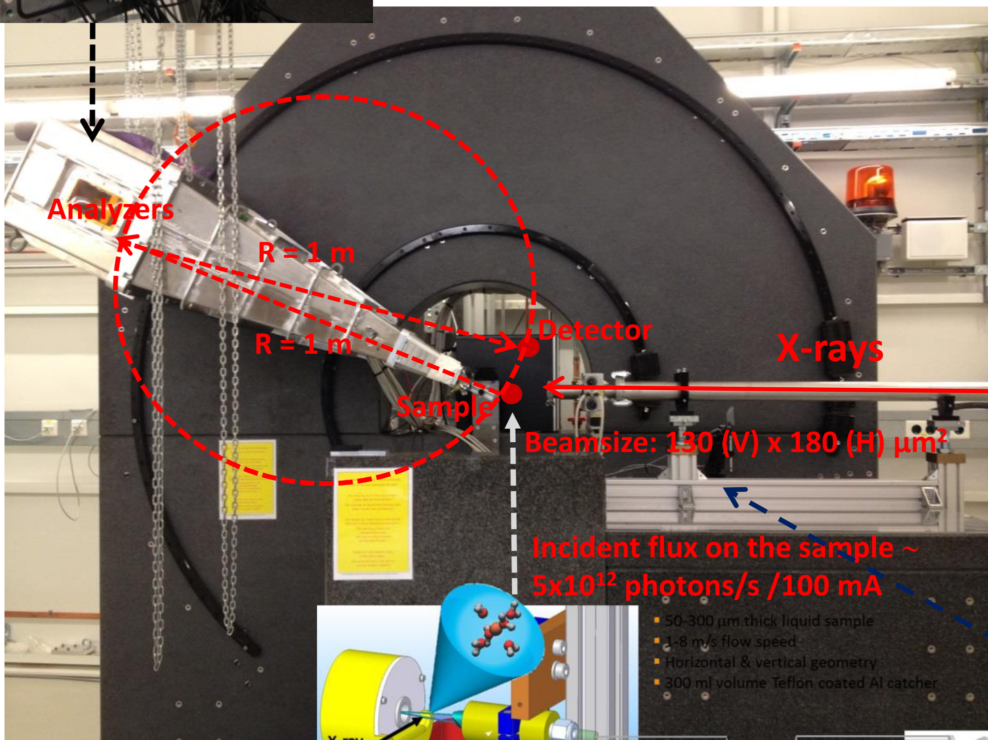


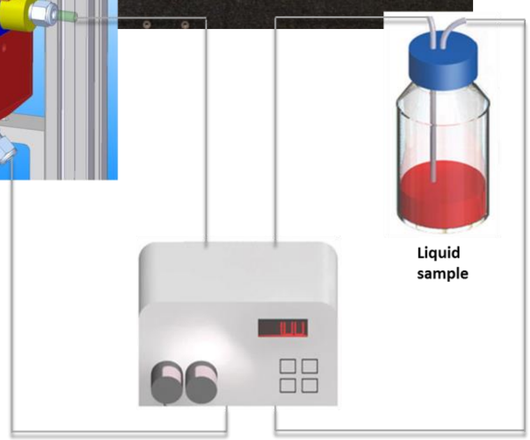


- previously published data via inelastic neutron scattering by *Stedman et al. J. Phys. F: Metal Phys.* ***6*** *(2) 157 (1976)*

Deneysel Düzenek II: X-Işını Raman Saçılma (XRS) Spektroskopisi







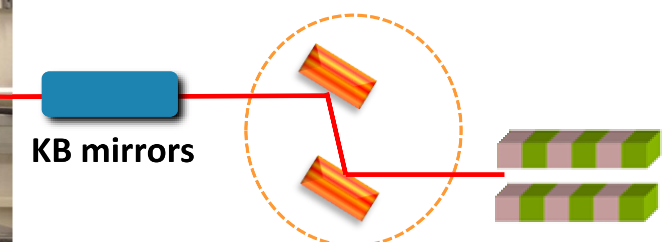
Liquid jet for liquid samples

Incident energy = 9.6 - 11.2 keV

Si(311)

Energy = 10 keV

ΔE ~ 250 meV



KB mirrors

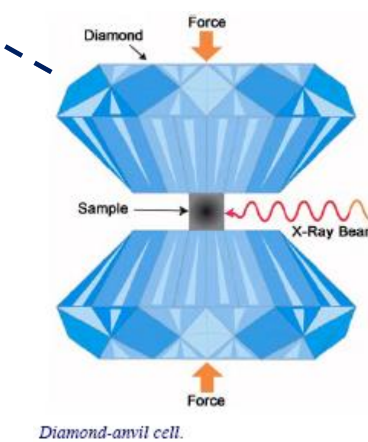
Double Crystal Monochromator (DCM)

U32 undulators

Length: (5m+5m)

Minimum gap: 12.7mm

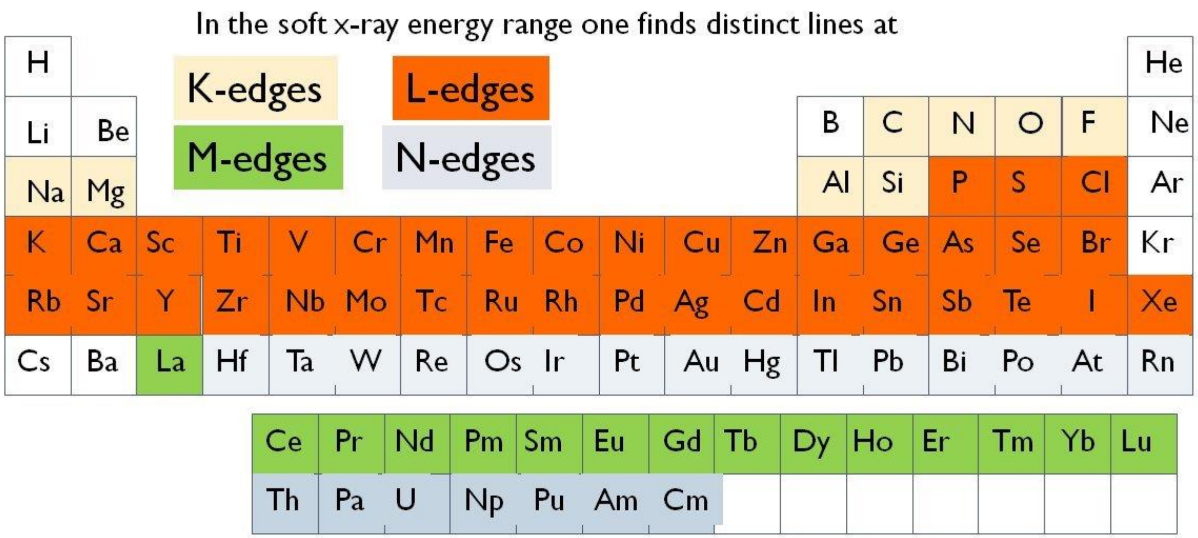
Energy: 4 keV – 11 keV

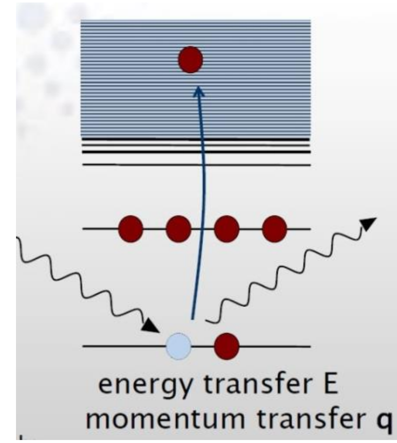


Diamond Anvil Cell

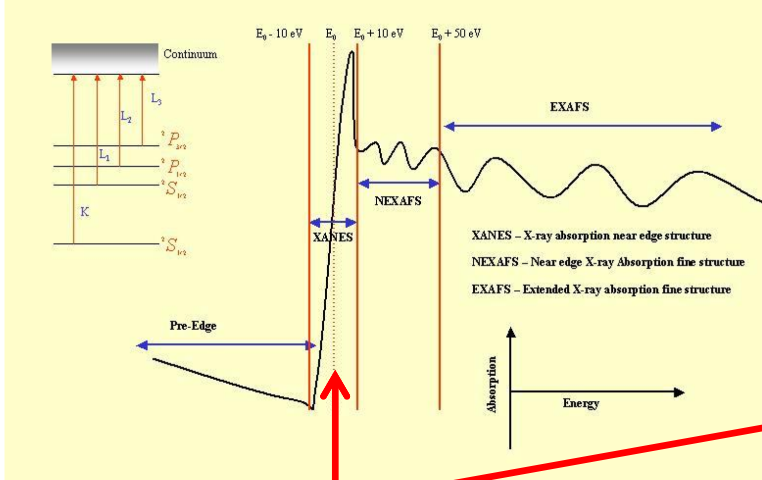
XRS Tekniği

Sert x-ışınları (~10 keV) ile yumuşak x-ışınları (50–1000 eV) bölgesindeki soğurma sınırlarının ölçümü





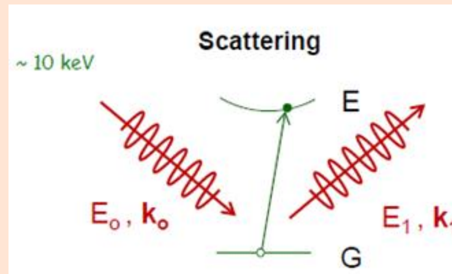
X-ışını soğurma spektrumu

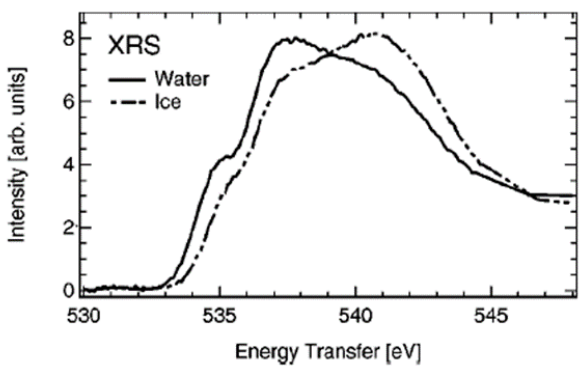


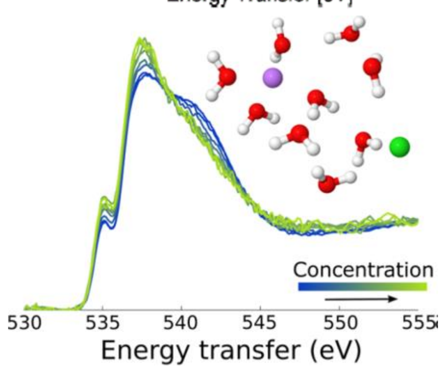
Soğurma sınırı

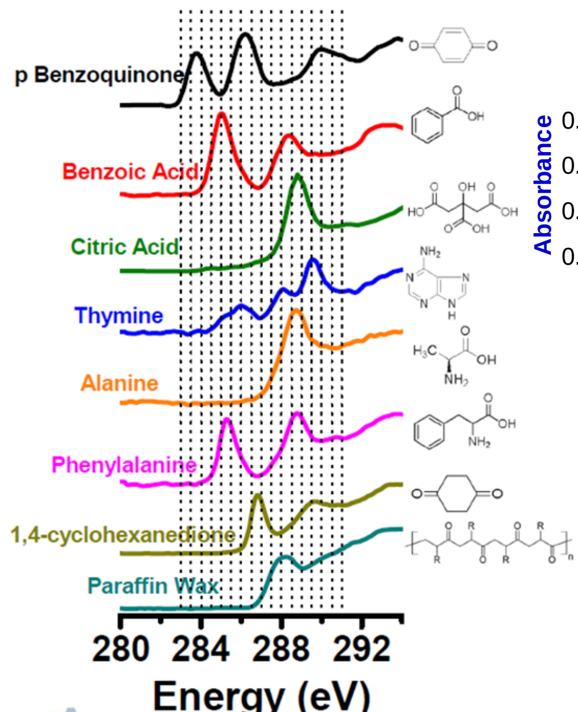
Local molecular and electronic structure

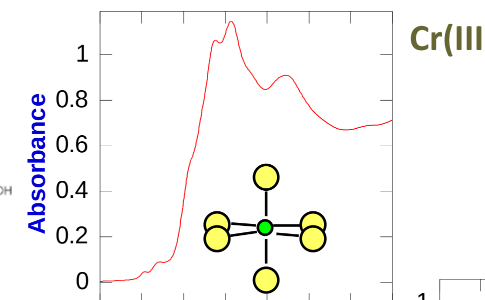
- ✓Identifying materials: solids, liquids, gas
- ✓Types of bonding
- ✓ Coordination number

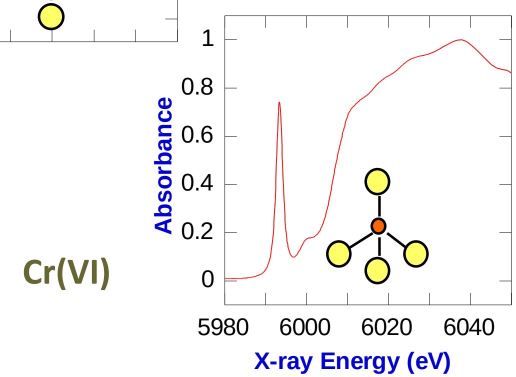




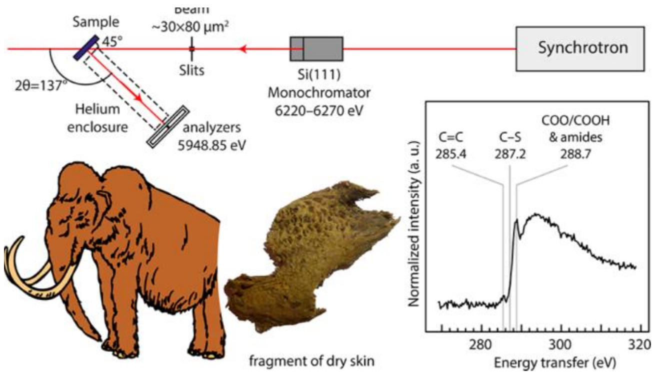




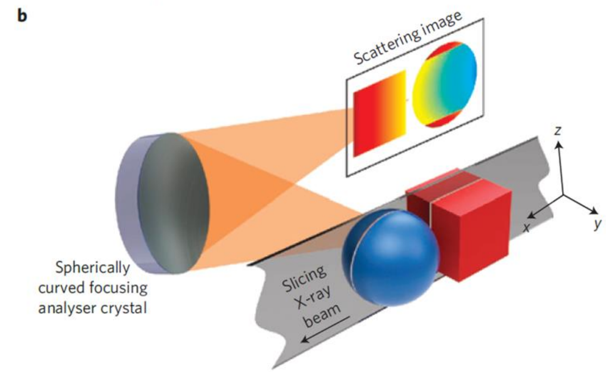




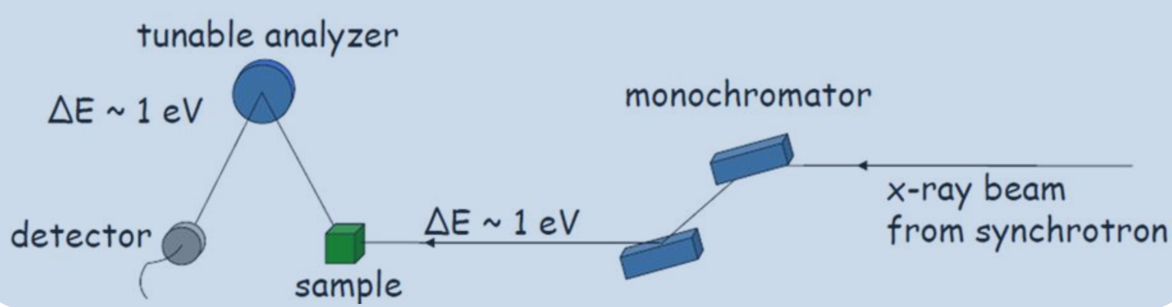
Discriminating Carbonaceous Compounds in Ancient samples



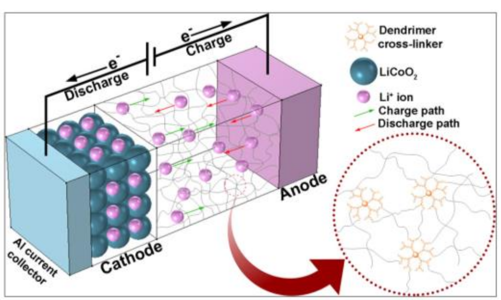
Direct tomography with chemical bond contrast



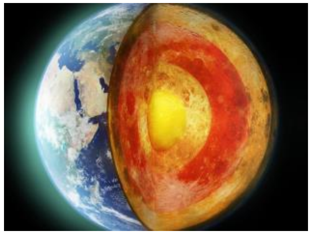
Applications

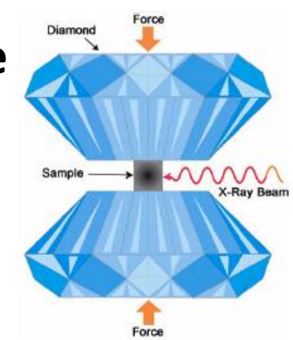


Rechargeable battery under working conditions



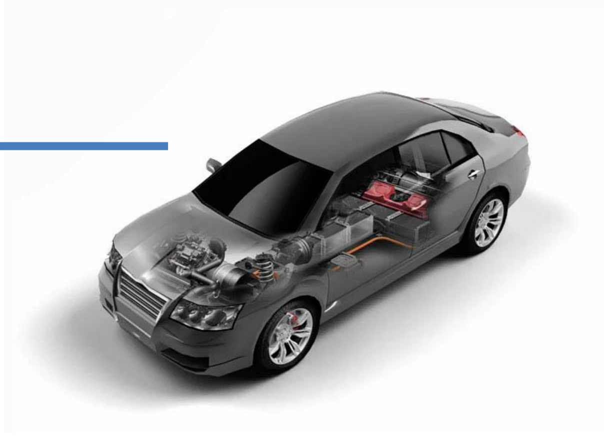
High pressure
High temperature



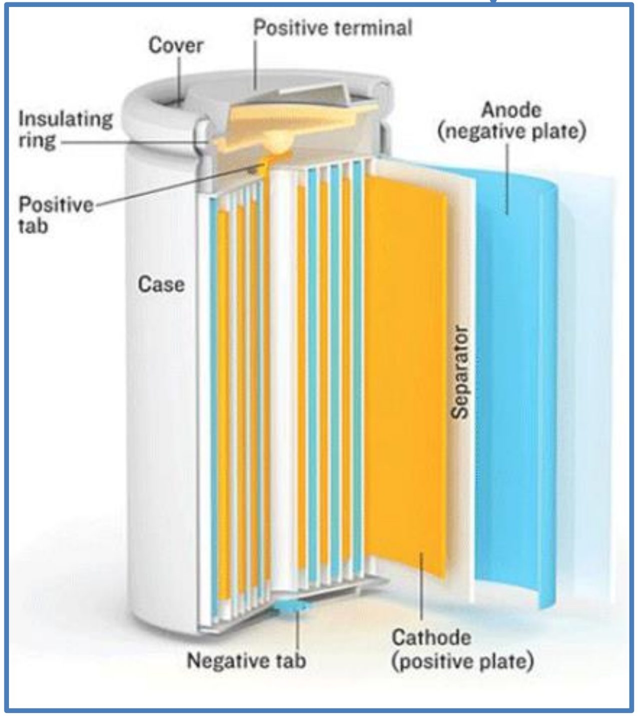


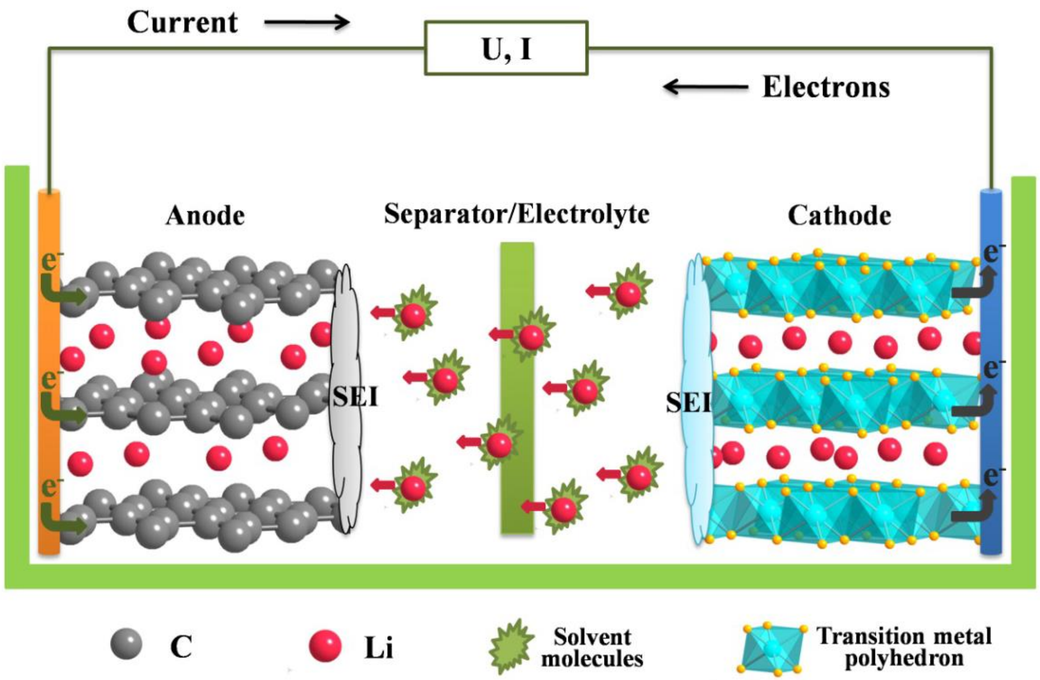
Diamond-anvil cell.

- Lityum iyon pilleri



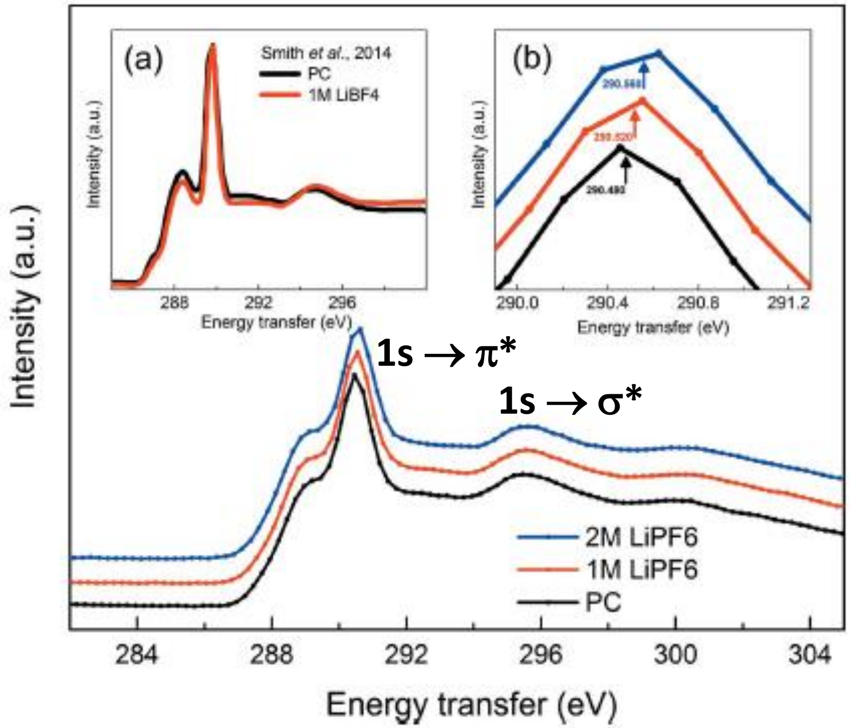
LIB cell structure

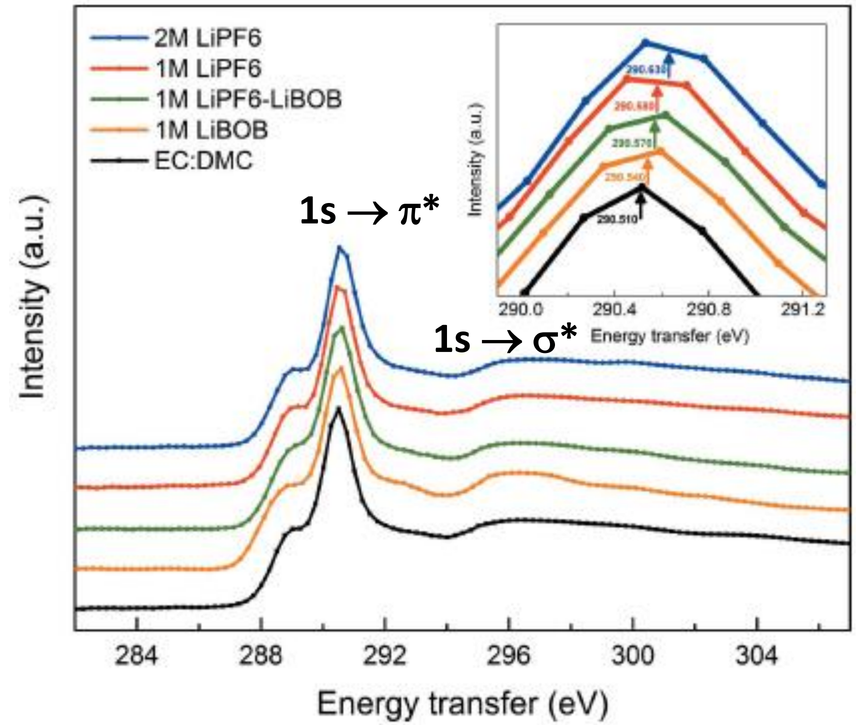




Carbon K-edge XRS spectra

D.Ketenoglu et al., J. Synchrotron Rad. 25 (2018) 537–542





Shifts relative to pure PC

1M $LiPF_6$ ➡ 0.04 eV

2M $LiPF_6$ ➡ 0.08 eV

Shifts relative to EC:DMC (1:1 vol.)

1 M LiBOB ➡ 0.03 eV

5 wt % LiBOB +$LiPF_6$ ➡ 0.06 eV

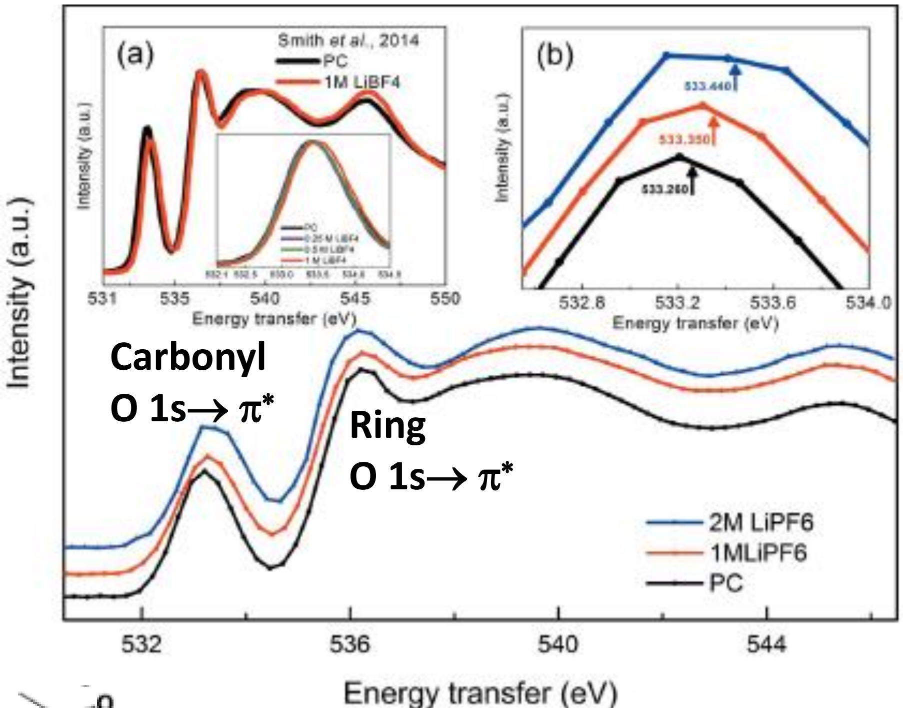
1M $LiPF_6$ ➡ 0.07 eV

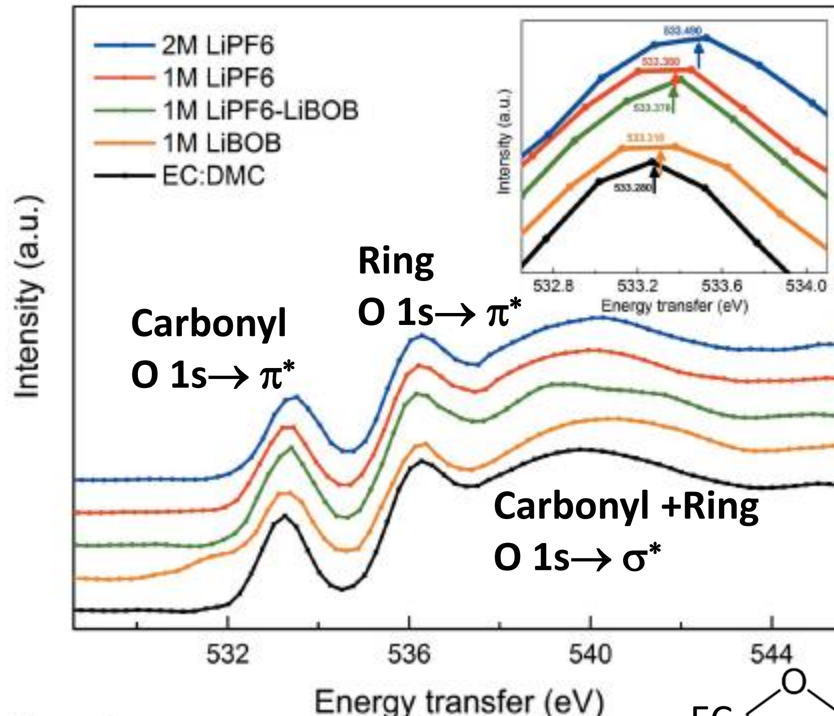
2M $LiPF_6$ ➡ 0.12 eV

(a) Phys. Chem. Chem. Phys. 16 (2014)23568–23575

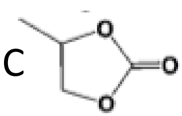
Oxygen K-edge XRS spectra

D.Ketenoglu et al., J. Synchrotron Rad. 25 (2018) 537–542

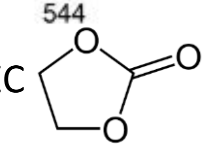




PC

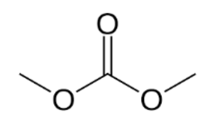


EC



Ring oxygens are unaffected by the addition of the salt

DMC



Carbonyl π*peak shifts relative to pure PC

1M $LiPF_6$ ➡ 0.06 eV
2M $LiPF_6$ ➡ 0.18 eV

Carbonyl π*peak shifts relative to EC:DMC (1:1 vol.)

1 M LiBOB ➡ 0.03 eV
5 wt % LiBOB +$LiPF_6$ ➡ 0.09 eV
1M $LiPF_6$ ➡ 0.1 eV
2M $LiPF_6$ ➡ 0.21 eV

(a) Phys. Chem. Chem. Phys. 16 (2014)23568–23575

References

- *D. Raoux, in Introduction to Synchrotron Radiation and to the Physics of Storage Rings, ed.by J. Baruchel et al. Neutron and Synchrotron Radiation for Condensed Matter Studies (Les Editions de Physique, Springer, 1993), pp. 37–78*
- *D. Ketenoglu et al., Resonant inelastic x-ray scattering spectrometer with 25 meV resolution, Journal of Synchrotron Radiation 22 Part 4 (2015) 961-967*
- *Ketenoglu D. (2019), Synchrotron Radiation: From Storage Ring to a Hard X-Ray Beamline. Uludağ Üniversitesi Mühendislik-Mimarlık Fakültesi Dergisi, 24(3), 75-88.*
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- *Lightsources of the World. http://www.lightsources.org/regions*