



# Hızlandırıcılara Dayalı Işınım Kaynakları-I (Sinkrotron Işınımı)

*Doç. Dr. Didem  
KETENOĞLU*

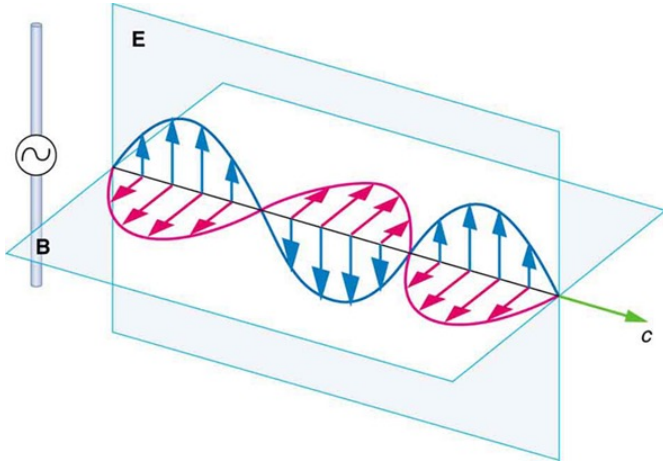
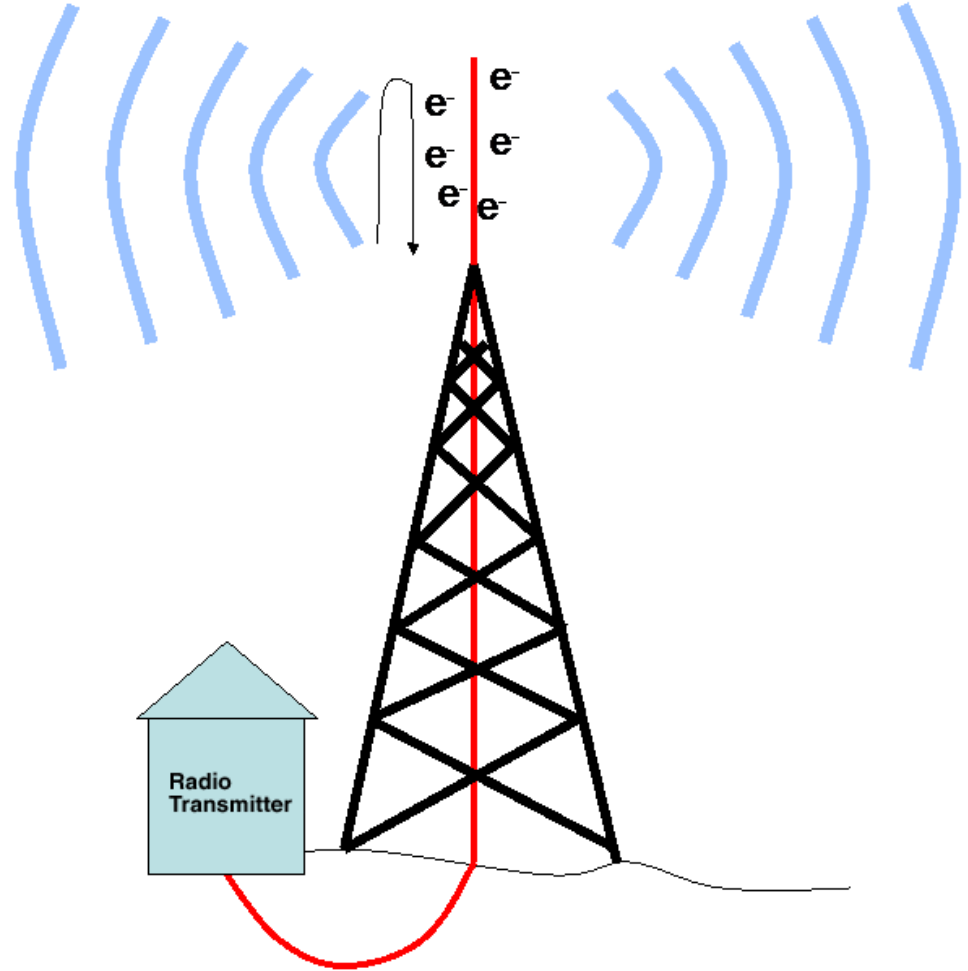
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dketen@eng.ankara.edu.tr*

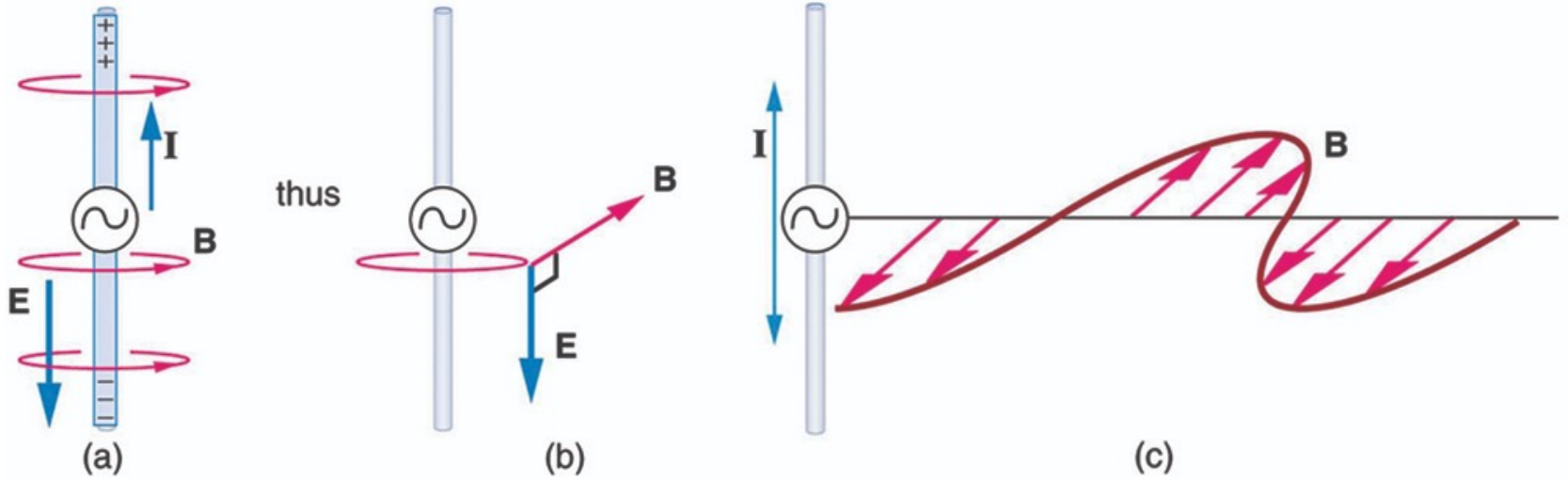
# İÇERİK

- ✓ **Sinkrotron Işınımı ve Özellikleri**
- ✓ **Sinkrotron Demet Hattı**
- ✓ **Sinkrotron Işınımının Kullanım Alanları**
- ✓ **Dünyadaki Sinkrotron Tesisleri**
- ✓ **DESY/PETRAIII Sinkrotronunda Gerçekleştirilen Deneysel Çalışmalardan Örnekler**
- ✓ **Türk Hızlandırıcı Merkezi Projesi**

# Elektromanyetik Radyasyon

Bir radyo anteninde aşağı ve yukarı **hızlandırılan** elektronlar radyo dalgaları yayınlar

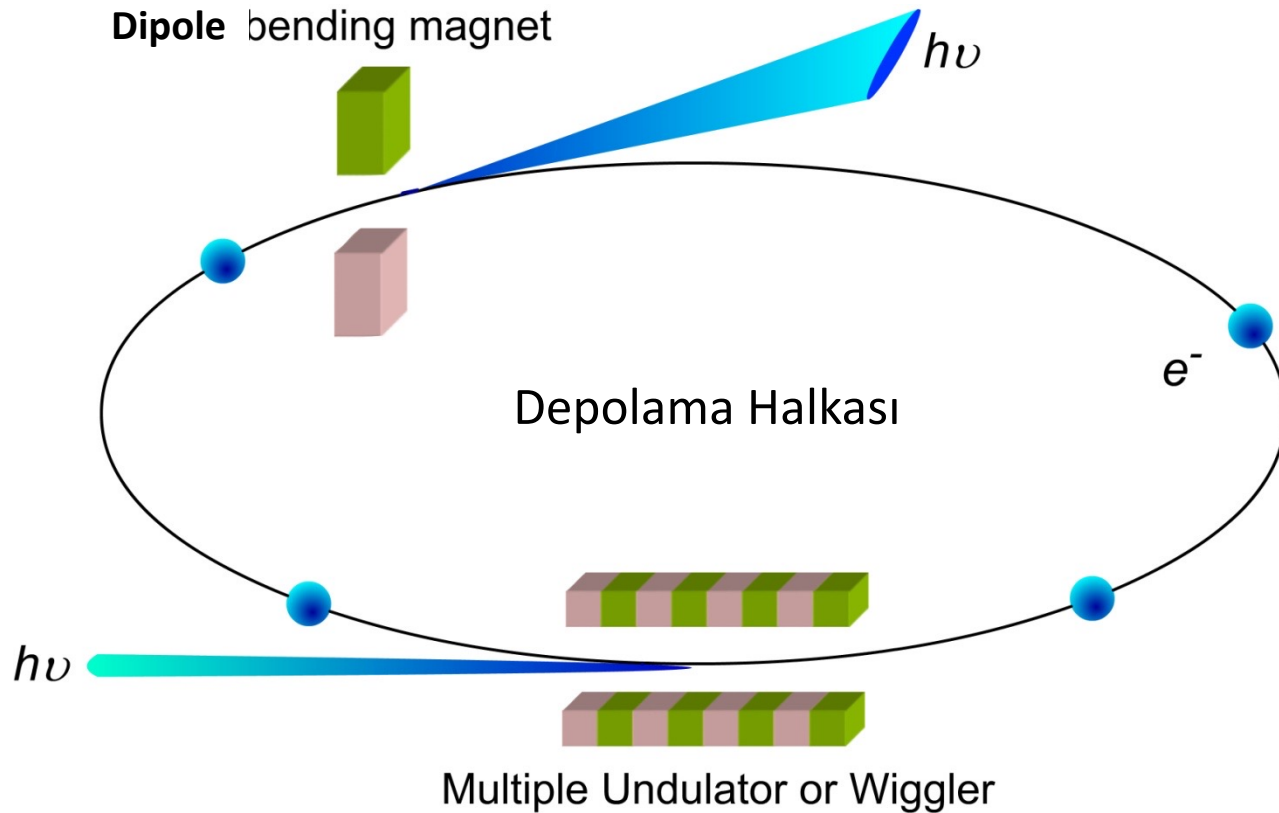




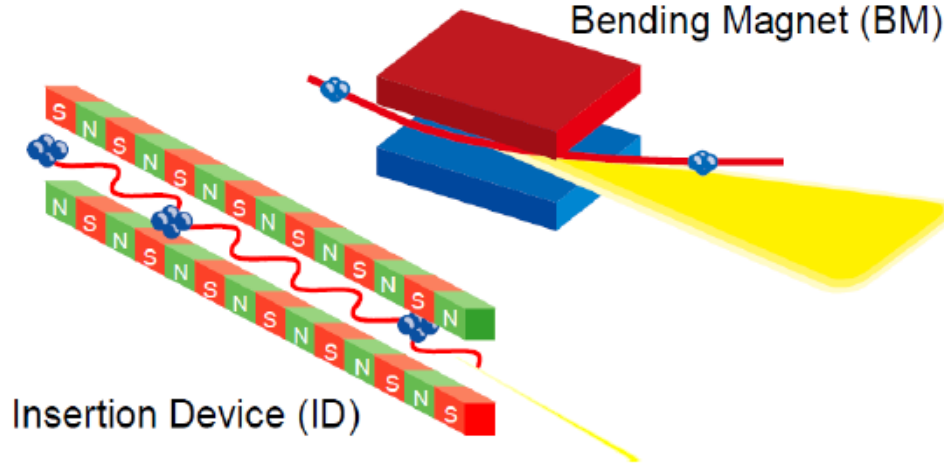
- İvmeli hareket eden yükler, değişen elektrik ve manyetik alanlar üretir.
- Değişen elektrik alanlar, manyetik alanları; değişen manyetik alanlar da, elektrik alanları üretir.
- İndüklenen elektrik ve manyetik alanlar arasındaki bu etkileşim, yayılan elektromanyetik dalgalara yol açar.

# 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



### **Bending/Dipole Magnet (Eğici Magnet):**

Dairesel hızlandırıcıların depolama halkasında bulunan elemanlarıdır. Parçacıkları sabit manyetik alan ile dairesel yörüngede tutarlar.

### **Insertion Devices (Eklenti Aygıtları):**

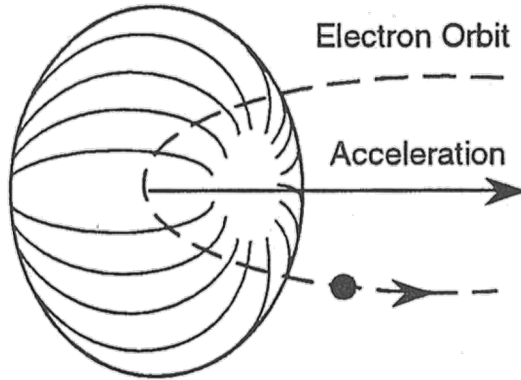
Elektron demetinin periyodik hareketini sağlayacak periyodik manyetik alan üretirler.

- **Wiggler (Zigzaglayıcı)**
- **Undulator (Salındırıcı)**

Işık hızına yakın hızlarda:

- Radyasyon gücü artar
- Radyasyon odaklanmış olarak elde edilir

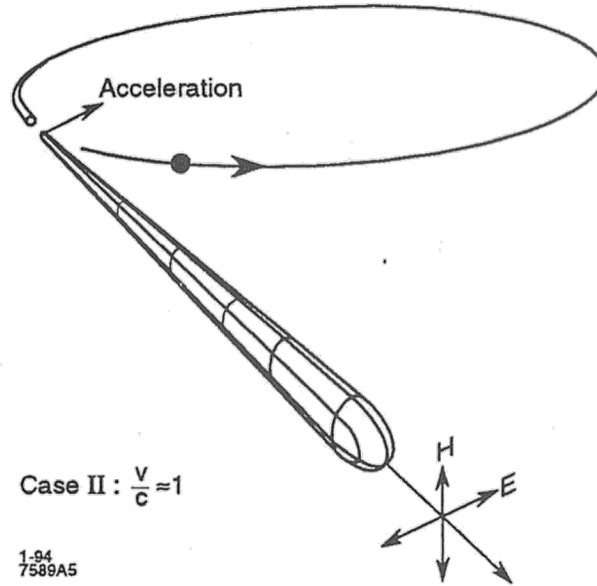
$$(v \perp a)$$



Case I :  $\frac{v}{c} \ll 1$

1-94  
7589A4

At low electron velocity (non-relativistic case) the radiation is emitted in a non-directional pattern



Case II :  $\frac{v}{c} \approx 1$

1-94  
7589A5

When the electron velocity approaches the velocity of light, the emission pattern is folded sharply forward. Also **the radiated power goes up dramatically**

Özel görelilik teorisine göre,  $v$  hızıyla hareket eden, durgun kütlesi  $m$  olan bir parçacığın kinetik enerjisi:

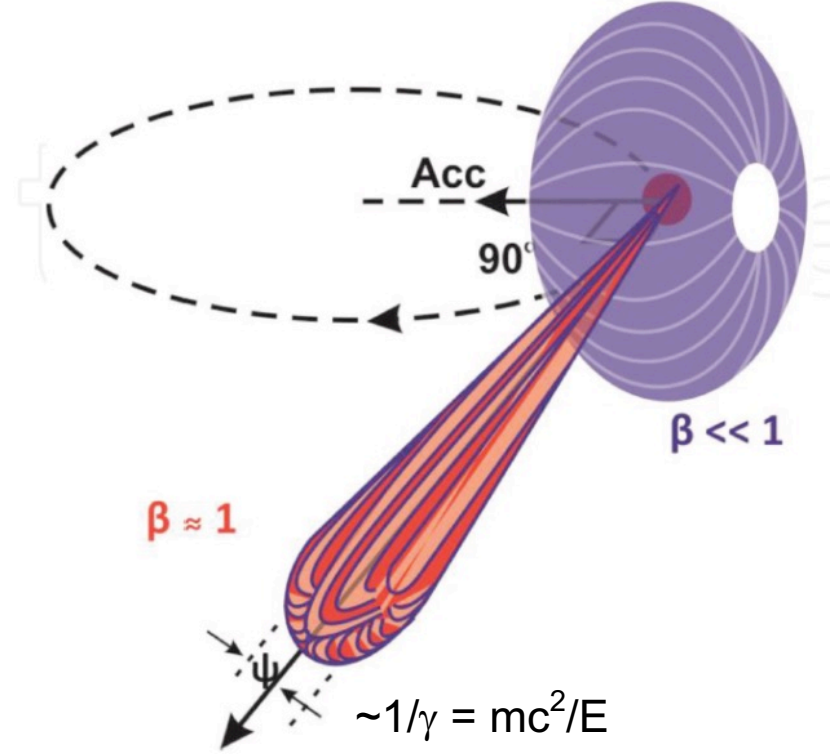
$$E = \frac{mc^2}{\sqrt{1 - \left(\frac{v}{c}\right)^2}}$$

$$= \frac{mc^2}{\sqrt{1 - (\beta)^2}}$$

$$\gamma = \frac{1}{\sqrt{1 - (\beta)^2}}$$

$$\beta = v / c$$

$\gamma$  : Lorentz Faktörü



Çembersel yörüngede hareket eden yüklü parçacıkların ışınım deseni

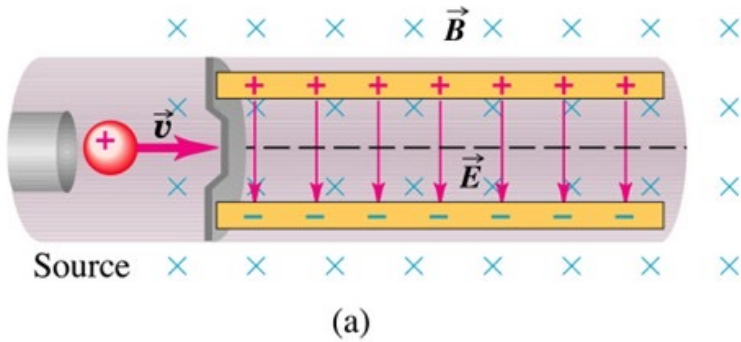
Işınım ileri yönde odaklıdır

Doğal SR diverjansı:  $1/\gamma \sim 100 \mu\text{rad}$  (elektronlar @ 5 GeV)

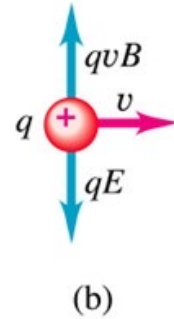


## Elektromanyetik Kuvvet (Lorentz Kuvveti)

$v$  hızı ile hareket eden  $q$  yükü  $E$  elektrik alanı ve  $B$  manyetik alanı ile verilen düzgün bir elektromanyetik alanda hareket ediyorsa, bu parçacığa etki eden elektromanyetik kuvvet (Lorentz kuvveti):



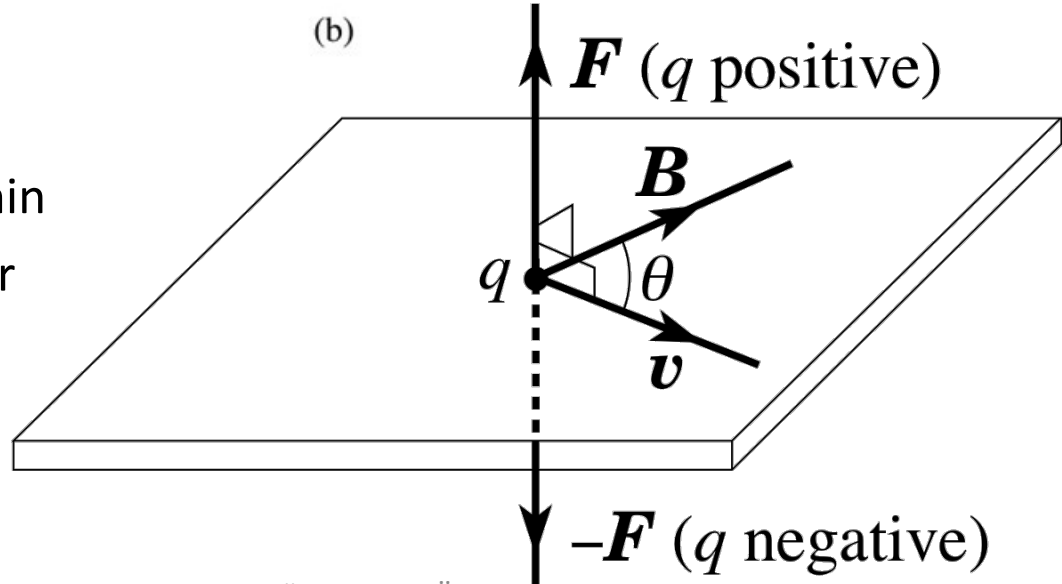
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$$\vec{F} = q\vec{E} + q\vec{v} \times \vec{B}$$

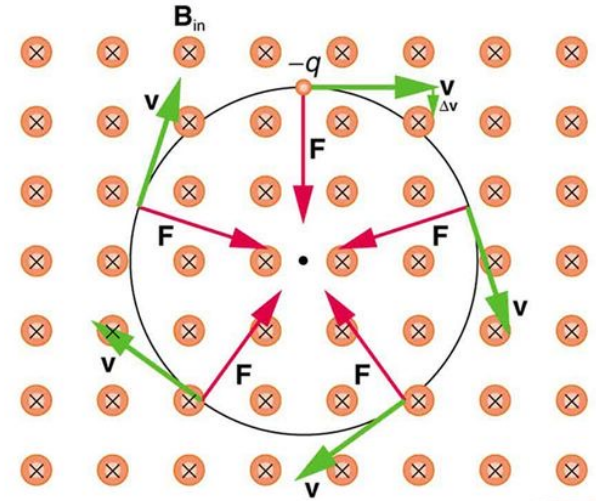
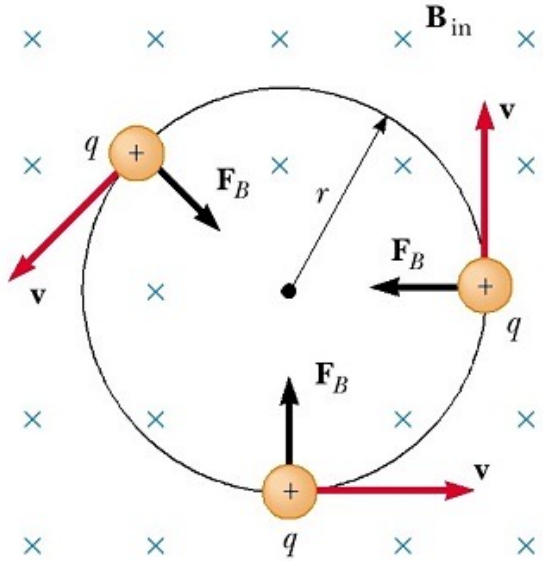
*Electric force*      *Magnetic force*

Manyetik kuvvet  $v$  ve  $B$ ' nin oluşturduğu düzleme diktir



# Merkezcil Kuvvet

$E = 0$  olsun.  $e^-$ ,  $B$  manyetik alanına dik olarak girerse ( $v \perp B$ ) manyetik kuvvet merkezcil kuvveti oluşturur ve parçacık  $r$  yarıçaplı çembersel yörünge üzerinde düzgün dairesel hareket yapar:



$$v \perp B \Rightarrow F_{\text{manyetik}} = F_{\text{merkezcil}}$$

$$evB \sin 90 = \frac{mv^2}{r}$$

$$evB = \frac{mv^2}{r}$$

Depolama halkasındaki elektronlar, yüklü parçacığın hareketine ve manyetik alan vektörüne dik bir Lorentz kuvveti uygulayan manyetik alanın etkisi altında kapalı bir yörüngede hareket ederler. Dairesel yörünge yarıçapı ( $r$ ) sabit kalmaktadır. Hız ve manyetik alan birbirine dik olduğundan:

$$e \vec{v} \times \vec{B} = \frac{mv^2}{r}$$

$\beta \approx 1$  ise,  $m$  ve  $v$  ; rölativistik kütle  $\gamma m$  and  $c$  ile yer değiştirmelidir:

$$\begin{aligned} ecB &= \frac{\gamma mc^2}{r} \\ \Rightarrow r &= \frac{\gamma mc}{eB} \\ &= \frac{E}{ecB} \end{aligned}$$

$$r[m] = 3.3 \frac{E[GeV]}{B[T]}$$

Magnetik alan ve depolama halkasının yarıçapı, demet enerjisine sınırlama getirir. Sinkrotron ışınım kaynağının karakteristik frekansı  $\Omega_c$  ;  $\gamma$  ve  $\Omega_0$  parametreleri cinsinden:

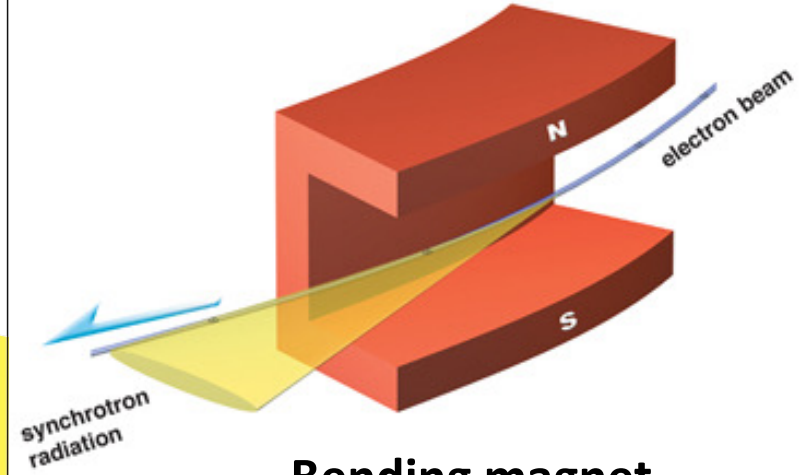
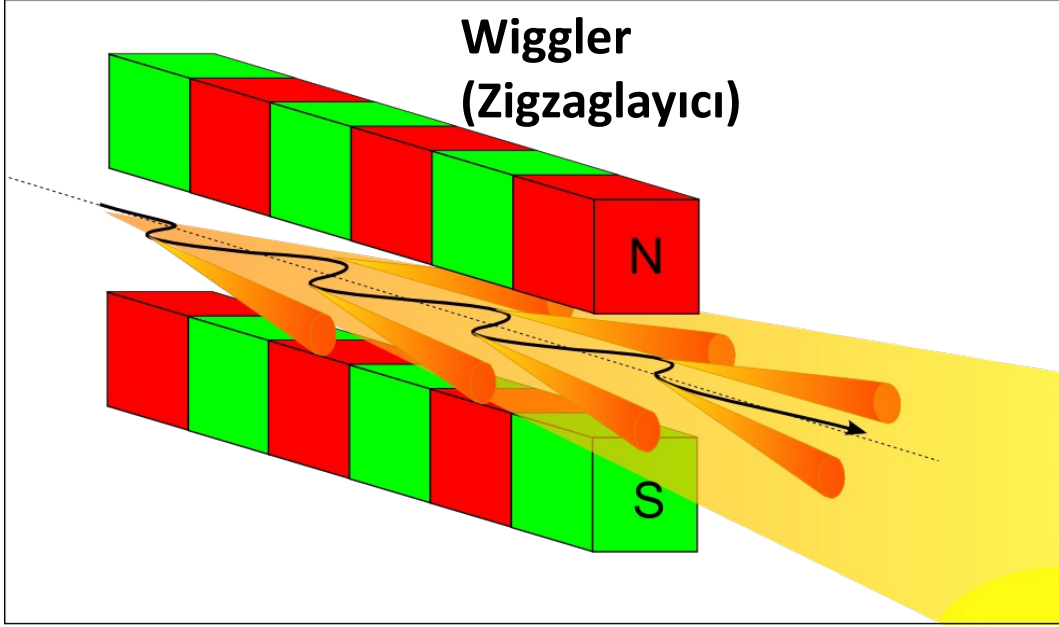
$$\Omega_c = \frac{3}{2} \gamma^3 \Omega_0 = \frac{3}{2} \gamma^3 \frac{c}{r}$$

Sinkrotron ışınım kaynağının kritik enerjisi, bending magnet'teki toplam güç yayılımının yarısıdır:

$$\hbar\Omega_c[keV] = 0.665 E^2[GeV]B[T]$$

Sinkrotron ışınım kaynağının kritik enerjisi depolama halkasının enerjisine ve bending magnet'in magnetik alanına bağlıdır

**Wiggler  
(Zigzaglayıcı)**

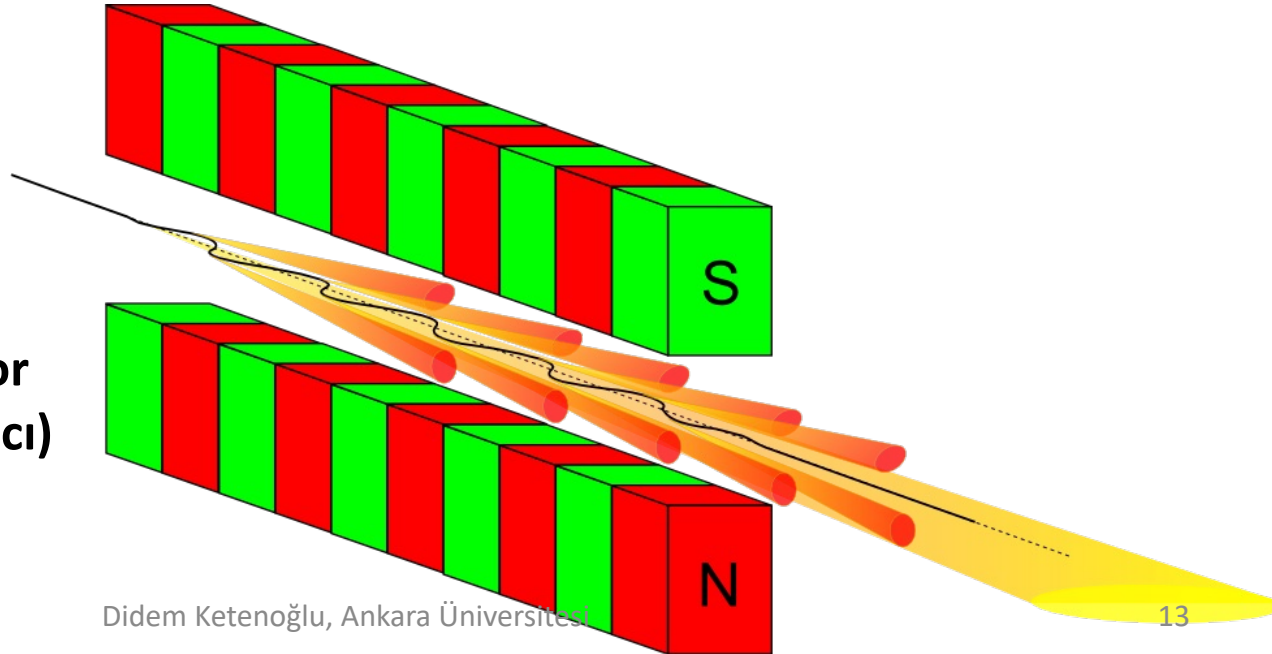


**Bending magnet  
(Eğici Magnet)**

**Insertion Devices  
(Eklenti Aygıtları):**

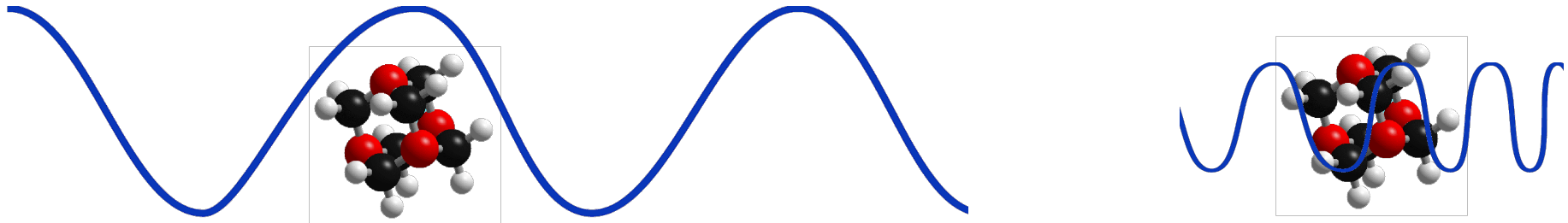
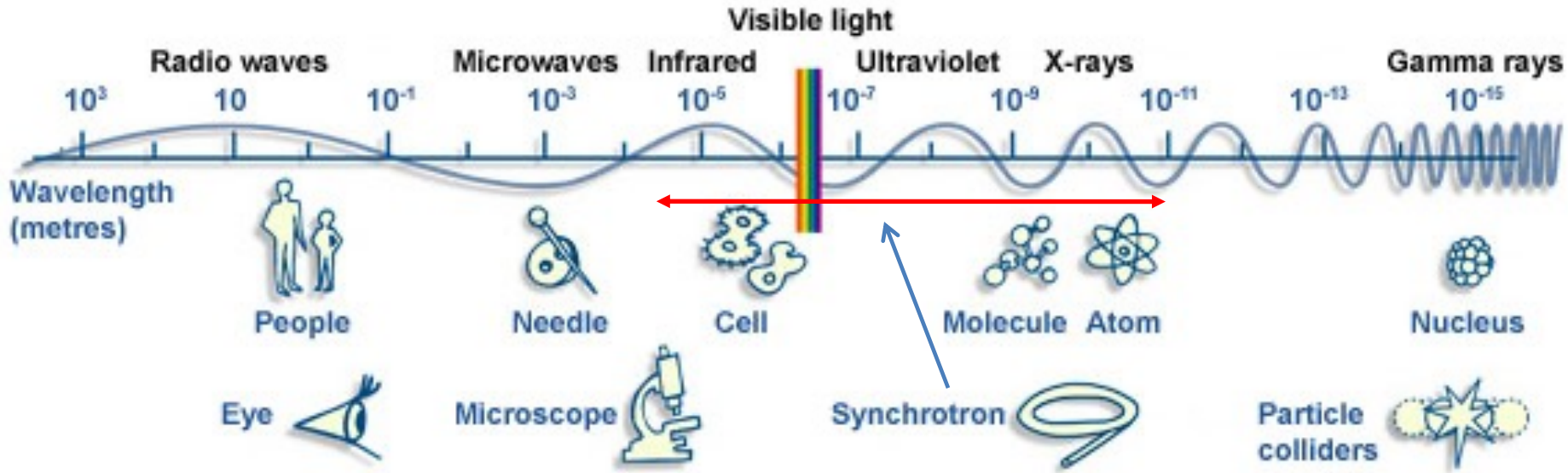
- Undulator
- Wiggler

**Undulator  
(Salındırıcı)**



# Sinkrotron Işınımının Özellikleri (I)

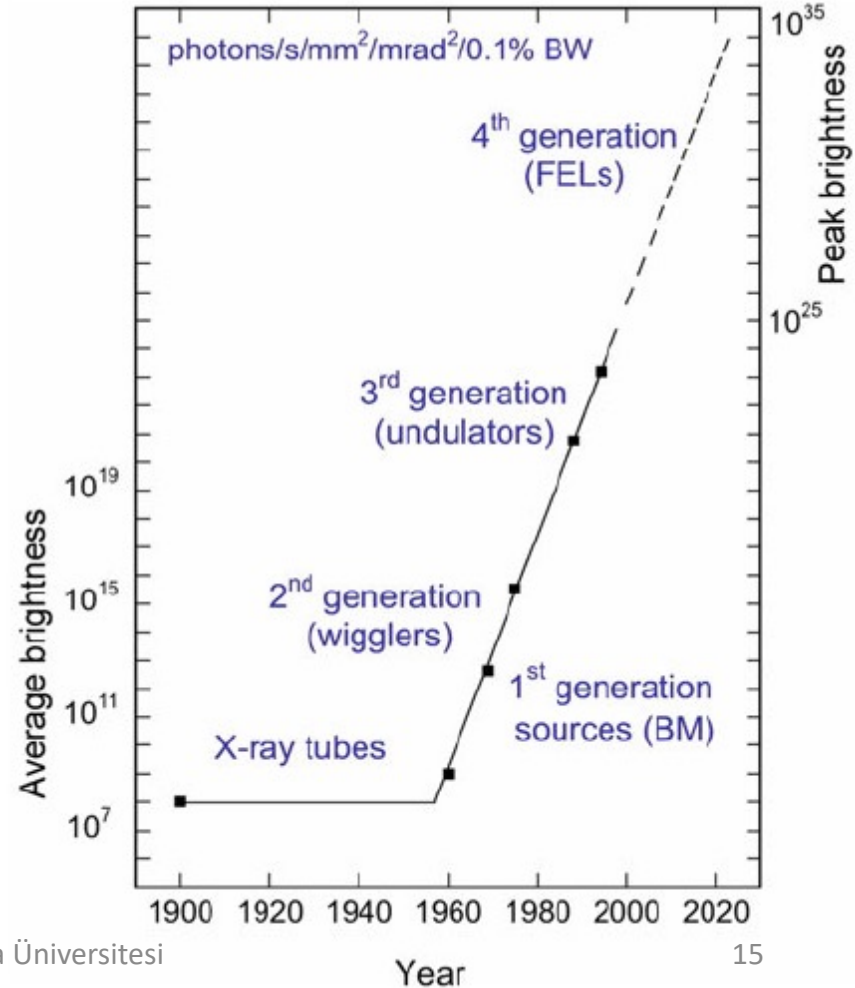
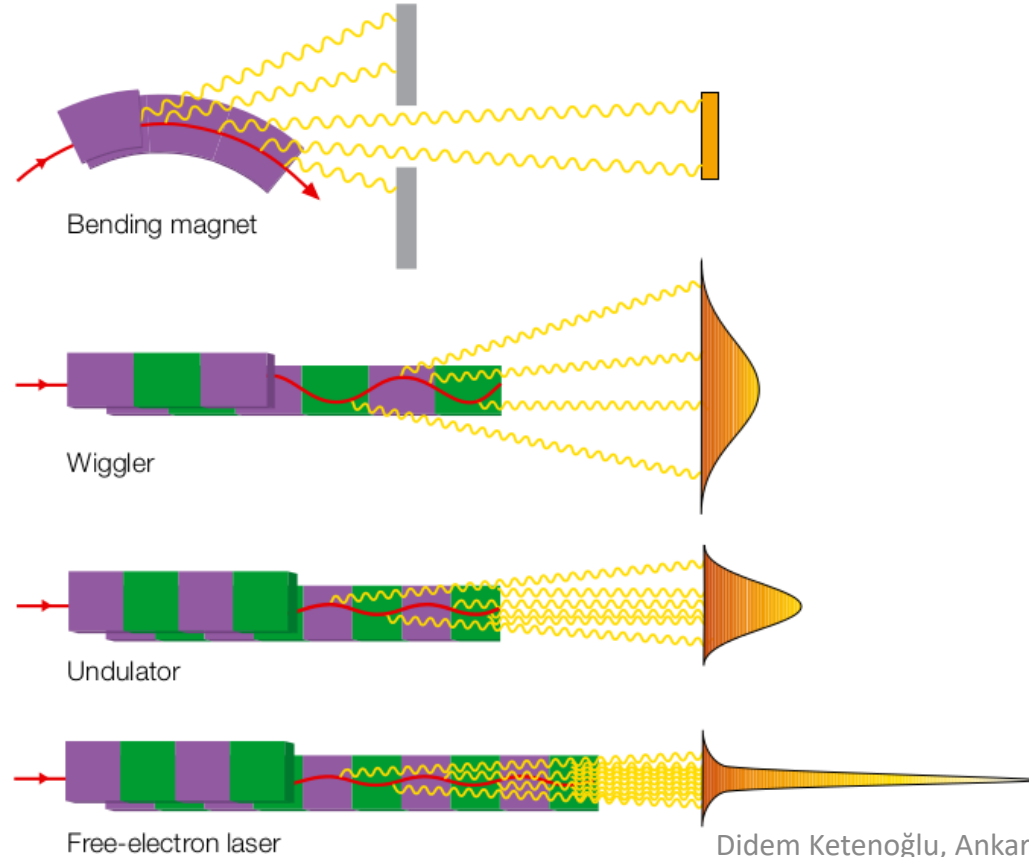
- Geniş spektral aralık



# Sinkrotron Işınımının Özellikleri (II)

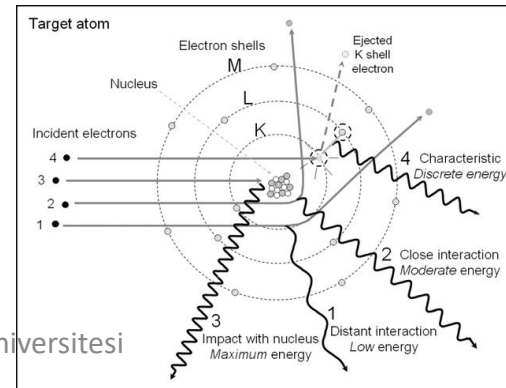
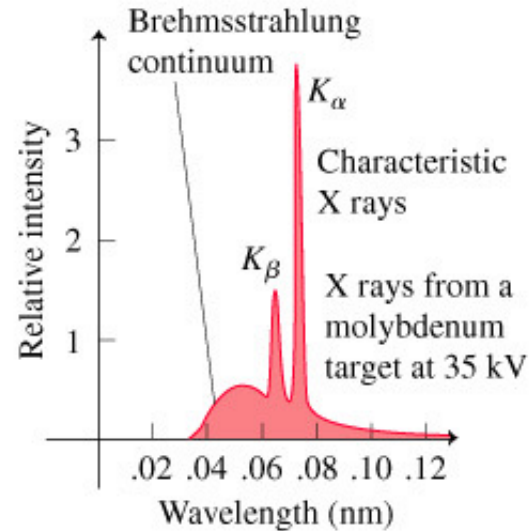
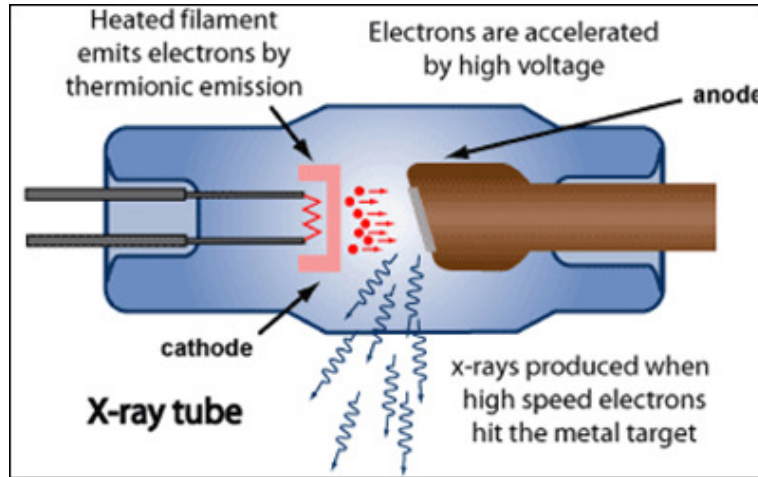
## • Yüksek Parlaklık

$$\text{Parlaklık} = \text{Foton} / (\text{s} \cdot \text{mm}^2 \cdot \text{mrad}^2 \cdot 0.1\% \text{ BW})$$



# X-Işını Tüpü

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



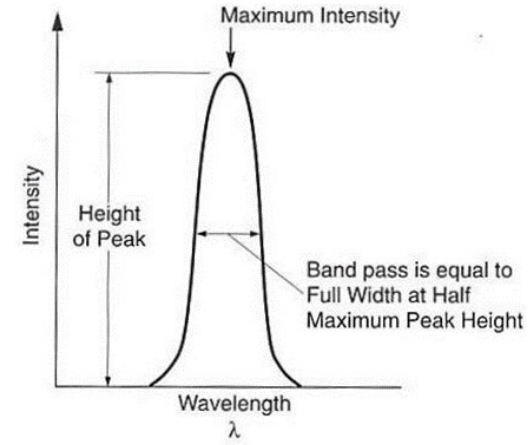


# Akı (Flux)

- **Akı (Flux)**; ışınım kaynağından bir saniyede, 0.1% bant genişliğinde (BW) yayılan foton sayısıdır.

$$\text{Flux} = \frac{\text{\# photons}}{\text{sec} \cdot 0.1\% \text{BW}}$$

- Akı, spektral saflığı hesaba katar
- Örneğin, 1000 eV' luk foton enerjisinde, 999.5-1000.5 eV bant dahilindeki foton/s akıya katkı sağlar.



**0.1% Bant Genişliği (BW):**  $\lambda$ 'nın 1/1000'ine eşit olan, belirli bir dalgaboyu ( $\lambda$ ) yakınındaki dalga boyu aralığı ( $\Delta\lambda$ )

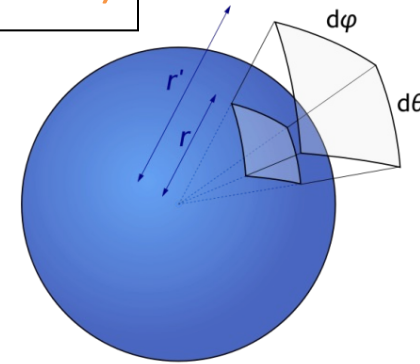
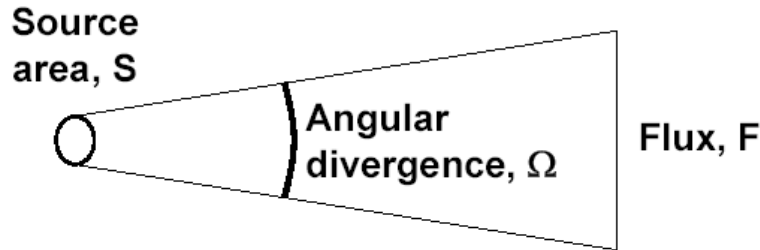
$$0.1\% \text{BW} = \frac{\Delta\lambda}{\lambda} = 10^{-3}$$

# Parlaklık (Brightness)

- Parlaklık (Brightness);** ışınım diverjansını hesaba kattığı için, deneyin gerçekleştiği noktadaki demet karakteristiğidir. Birim katı açı başına yayılan akıya eşittir.

$$\text{Brightness} = \frac{\text{\# photons}}{\text{sec} \cdot \text{mrad}^2 \cdot 0.1\% \text{BW}}$$

(a measure of concentration of the radiation)



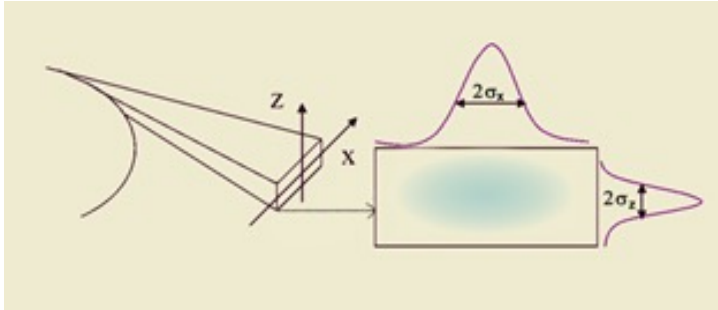
$$\text{Brightness} = \frac{\text{\# of photons in given } \Delta\lambda/\lambda}{\text{sec, mrad } \theta, \text{ mrad } \phi}$$

(a measure of concentration of the radiation)

# Aydınlık (Brilliance)

- Aydınlık (Brilliance)**; demet boyutlarını hesaba katan demet karakteristiğidir, mm<sup>2</sup> başına parlaklığa (brightness) eşittir (  $\sigma_x \sigma_z$  çarpımından gelir).

$$\text{Brilliance} = \frac{\# \text{ photons}}{\text{sec} \cdot \text{mrad}^2 \cdot \text{mm}^2 \cdot 0.1\% \text{BW}}$$



Brilliance: Flux/Emittance

$$B = \frac{n_{ph}}{\Delta t \cdot \epsilon_x \cdot \epsilon_z \cdot 0.1\% \text{BW}}$$

$$[B] = \frac{\text{photons}}{\text{s} \cdot \text{mm}^2 \cdot \text{mrad}^2 \cdot 0.1\% \text{BW}}$$

Yatay ve dişey yönlerde yayınım (emittance):

$$\epsilon_x = \sigma_x \sigma'_x \quad \sigma'_x \sigma'_z \text{ birimi [sterad] yerine [rad}^2\text{]}$$

$$\epsilon_z = \sigma_z \sigma'_z$$

$$\text{SR Emittance} = \Delta A \cdot \Delta \Omega$$

$\Delta A$ : source area  
 $\Delta \Omega$ : solid angle

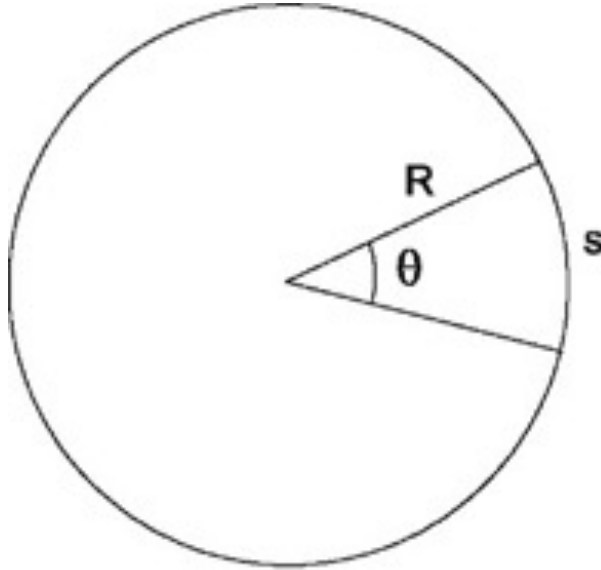
units: [nm·rad] -> [pm·rad]

$$\text{SR Brilliance} = \frac{\text{photon flux}}{\Delta A \cdot \Delta \Omega \cdot \Delta \lambda / \lambda}$$

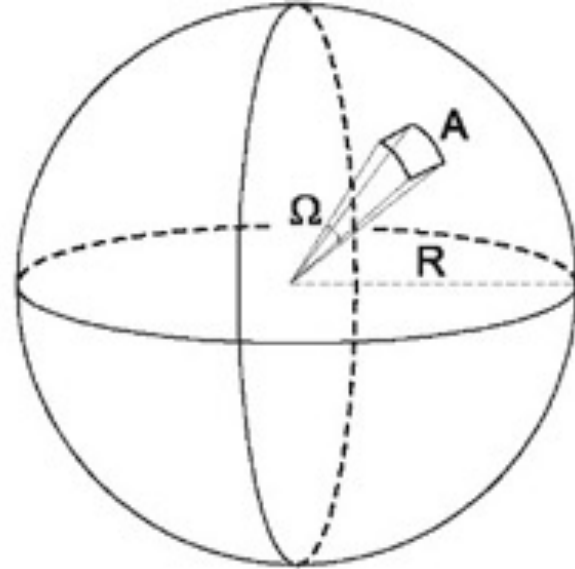
$\Delta \lambda / \lambda$ : spectral bandwidth

units:  $\frac{\text{number of photons}}{\text{s} \cdot \text{mrad}^2 \cdot \text{mm}^2 \cdot 0.1\% \text{bandwidth}}$

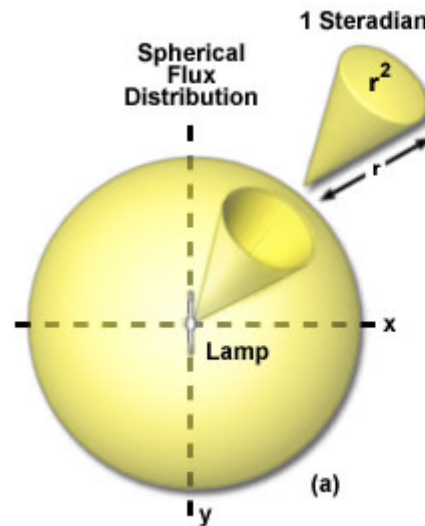
Both emittance and brilliance are **invariant quantities** in phase space → optical techniques cannot improve them!



$$\theta = \frac{s}{R} \text{ radians}$$



$$\Omega = \frac{A}{R^2} \text{ steradians (sr)}$$



• 60 Watt'lık ampul



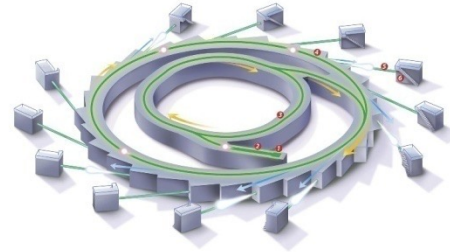
Parlaklık:  $10^6$  Foton / (s · mm<sup>2</sup> · mrad<sup>2</sup> · 0.1% BW)

• Güneş



Parlaklık:  $10^{10}$  Foton / (s · mm<sup>2</sup> · mrad<sup>2</sup> · 0.1% BW)

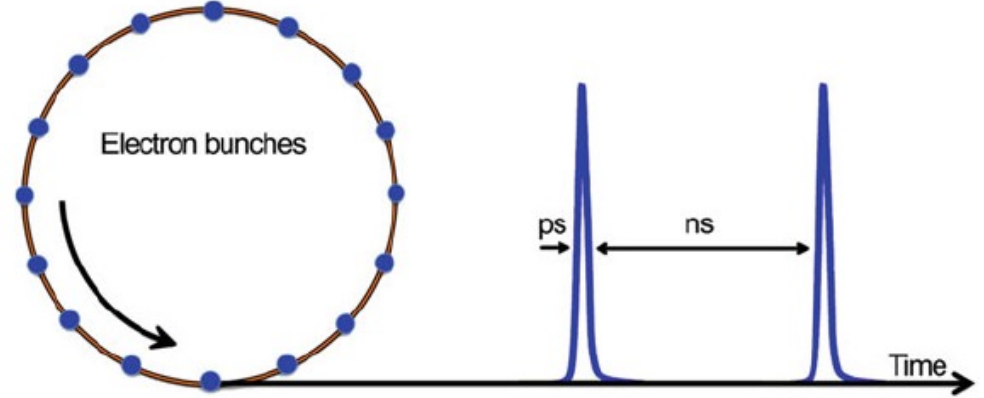
• 3.Nesil sinkrotron ışınım kaynağı



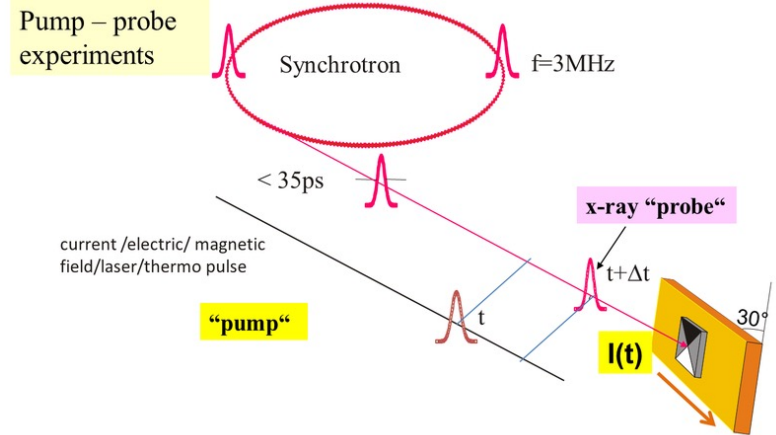
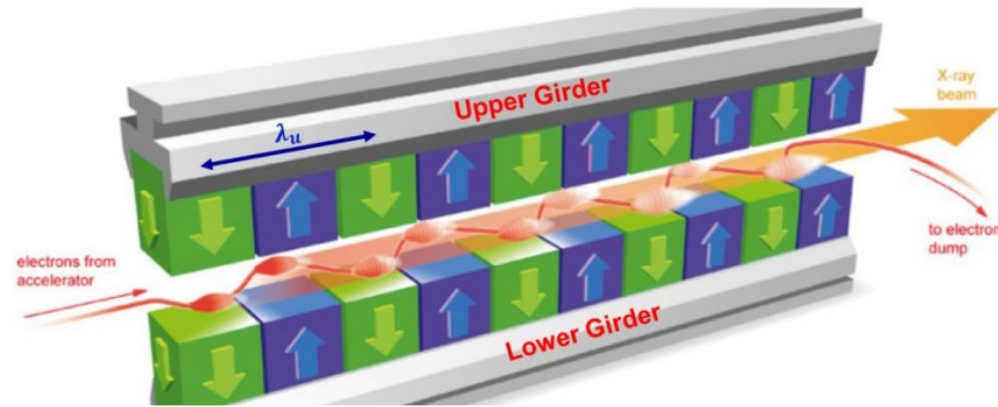
Parlaklık:  $10^{20}$  Foton / (s · mm<sup>2</sup> · mrad<sup>2</sup> · 0.1% BW)

# Sinkrotron Işınımının Özellikleri (III)

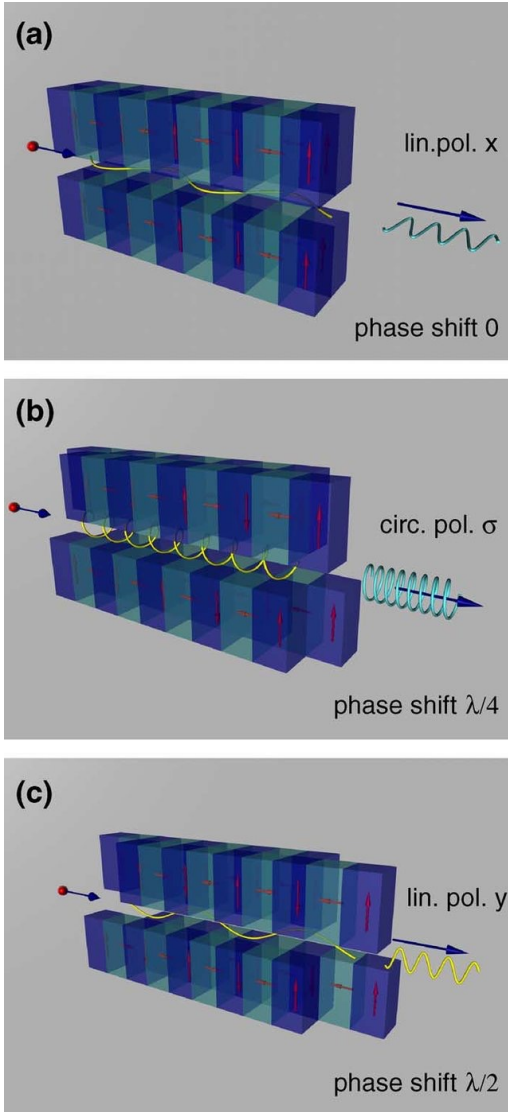
- Atmalı zaman yapısı



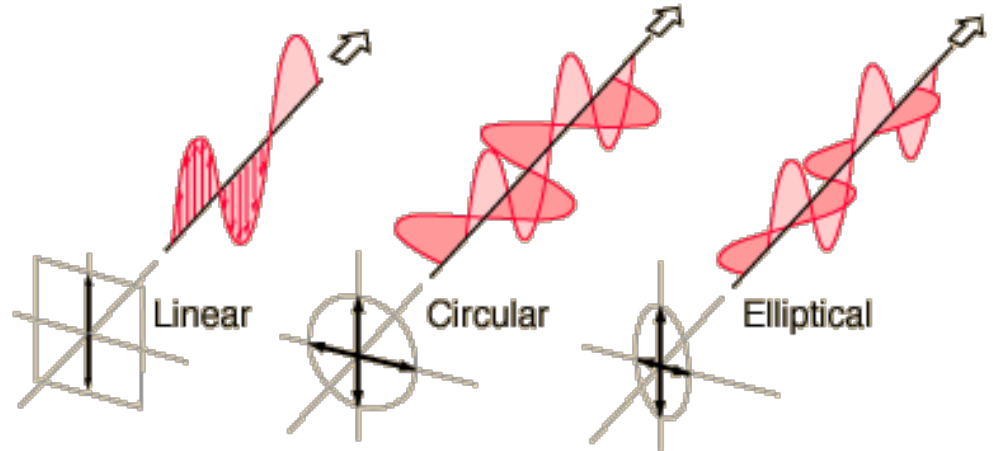
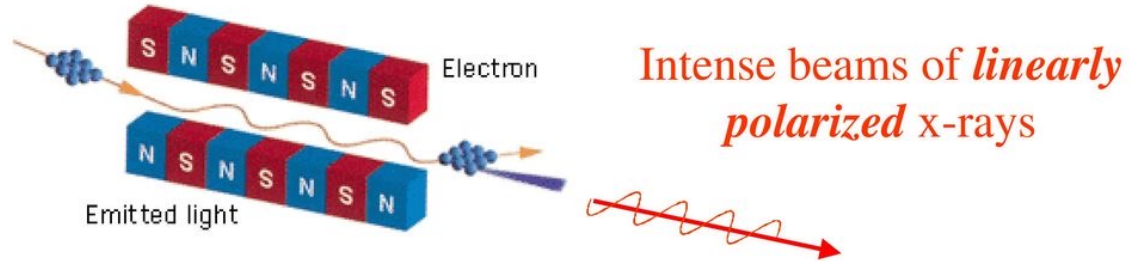
Electron bunches moving in the storage ring produce radiation peaks having the same bunch length (ps) and separation (ns)



## Kutuplu

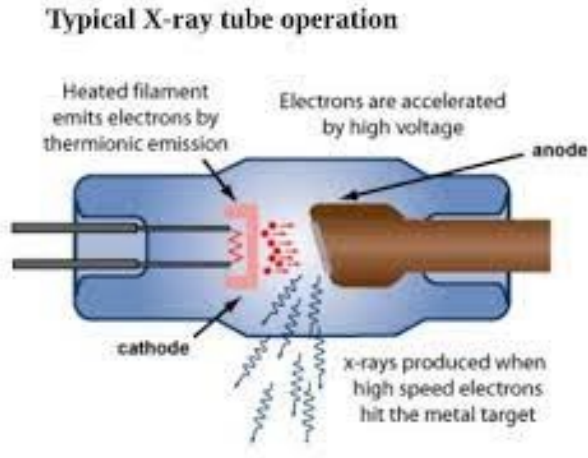


## Polarization of Synchrotron Radiation

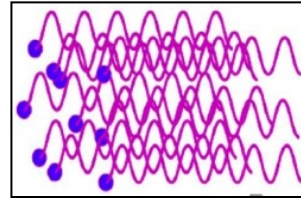




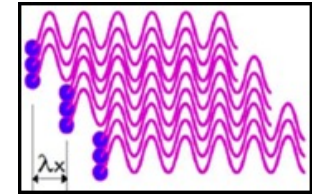
- **Kısmen koherent**



SR



X-FEL



- **Yüksek kararlılık:** Sinkrotron ışınım kaynağında mikron-altı kararlılık

# Dairesel-Doğrusal Hızlandırıcı

Sinkrotron

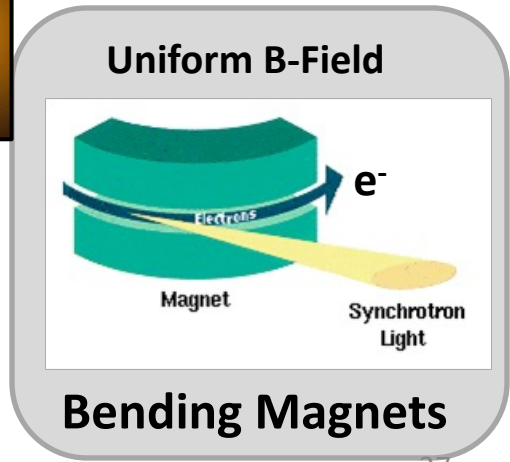
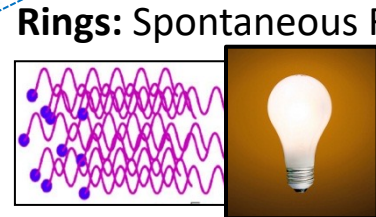
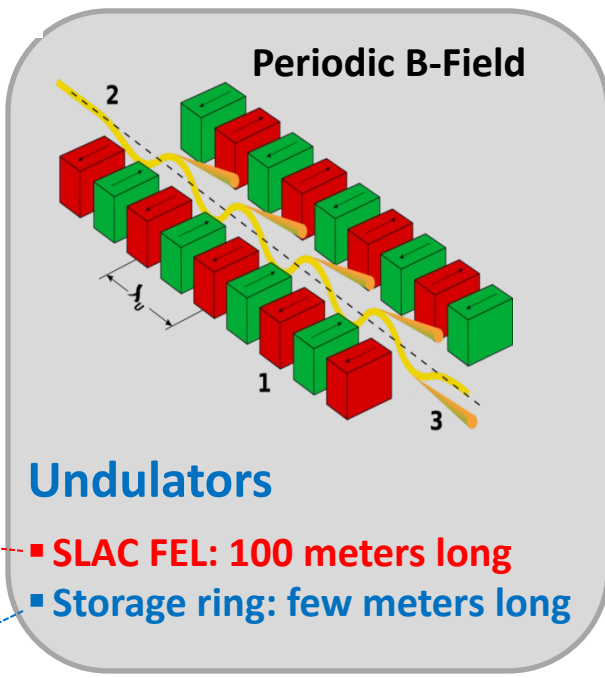
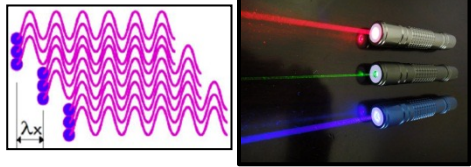
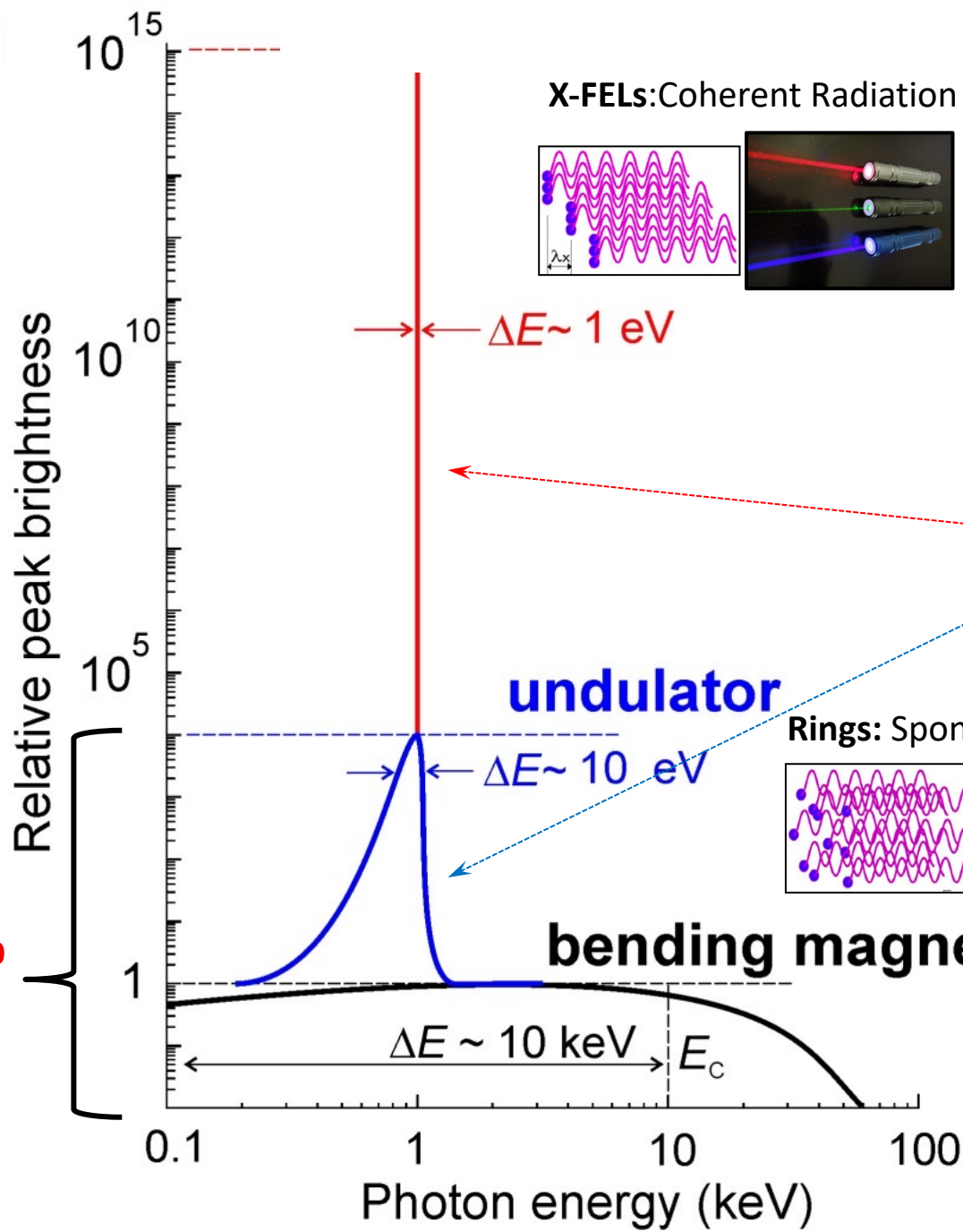
FEL



Dairesel hızlandırıcılarda; parçacıklar dairesel yörüngeyi defalarca dolanır

Doğrusal hızlandırıcılarda; parçacıklar hızlandırıcı yapıdan sadece bir kez geçerler

storage ring



# Sinkrotronun Şematik Görünümü

1

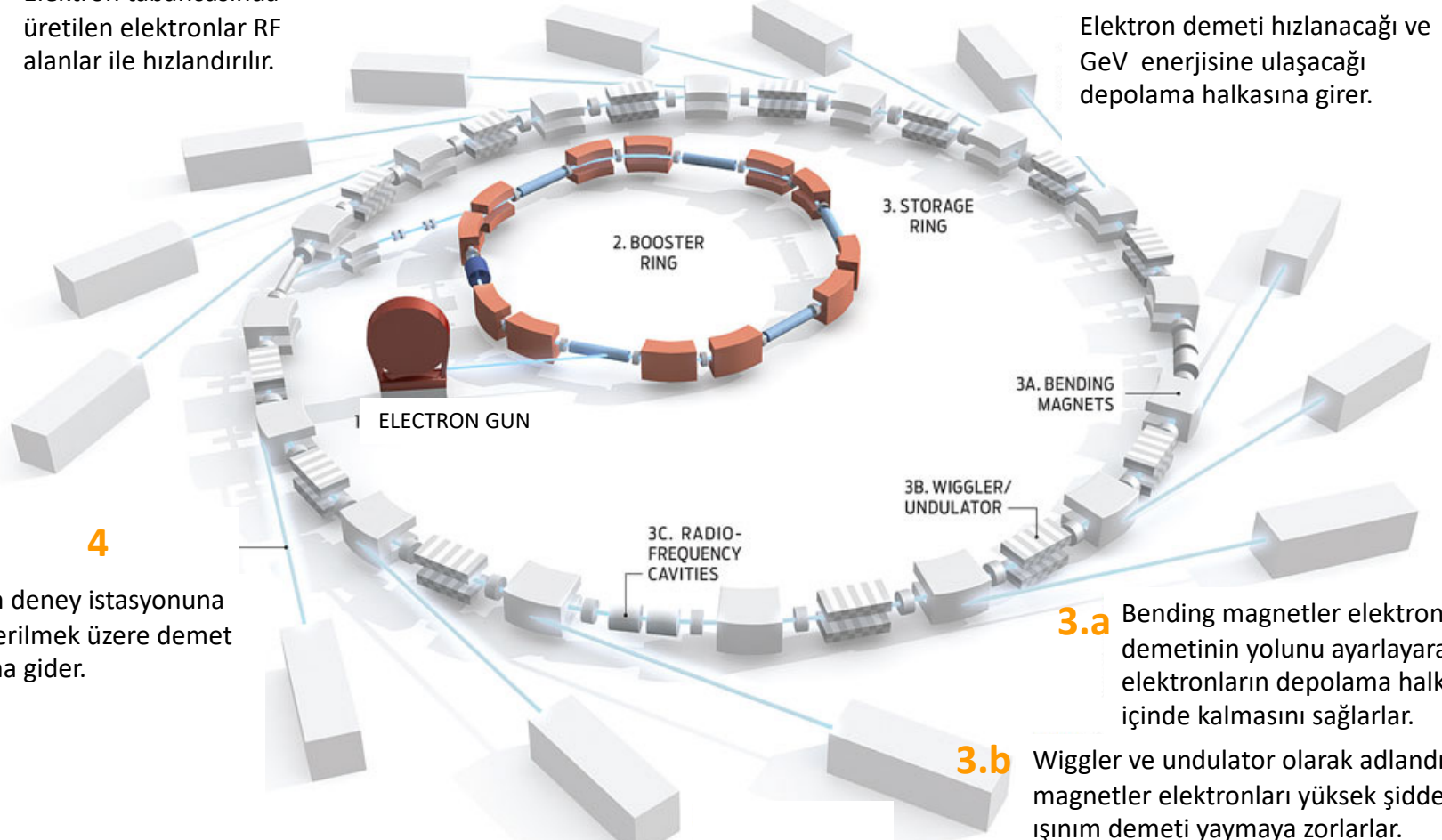
Elektron tabancasında üretilen elektronlar RF alanlar ile hızlandırılır.

2

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

3

Elektron demeti hızlanacağı ve GeV enerjisine ulaşacağı depolama halkasına girer.



4

Işınım deney istasyonuna gönderilmek üzere demet hattına gider.

3.c

RF kaviteler, elektronlara kaybettikleri enerjiyi geri kazandırır.

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.

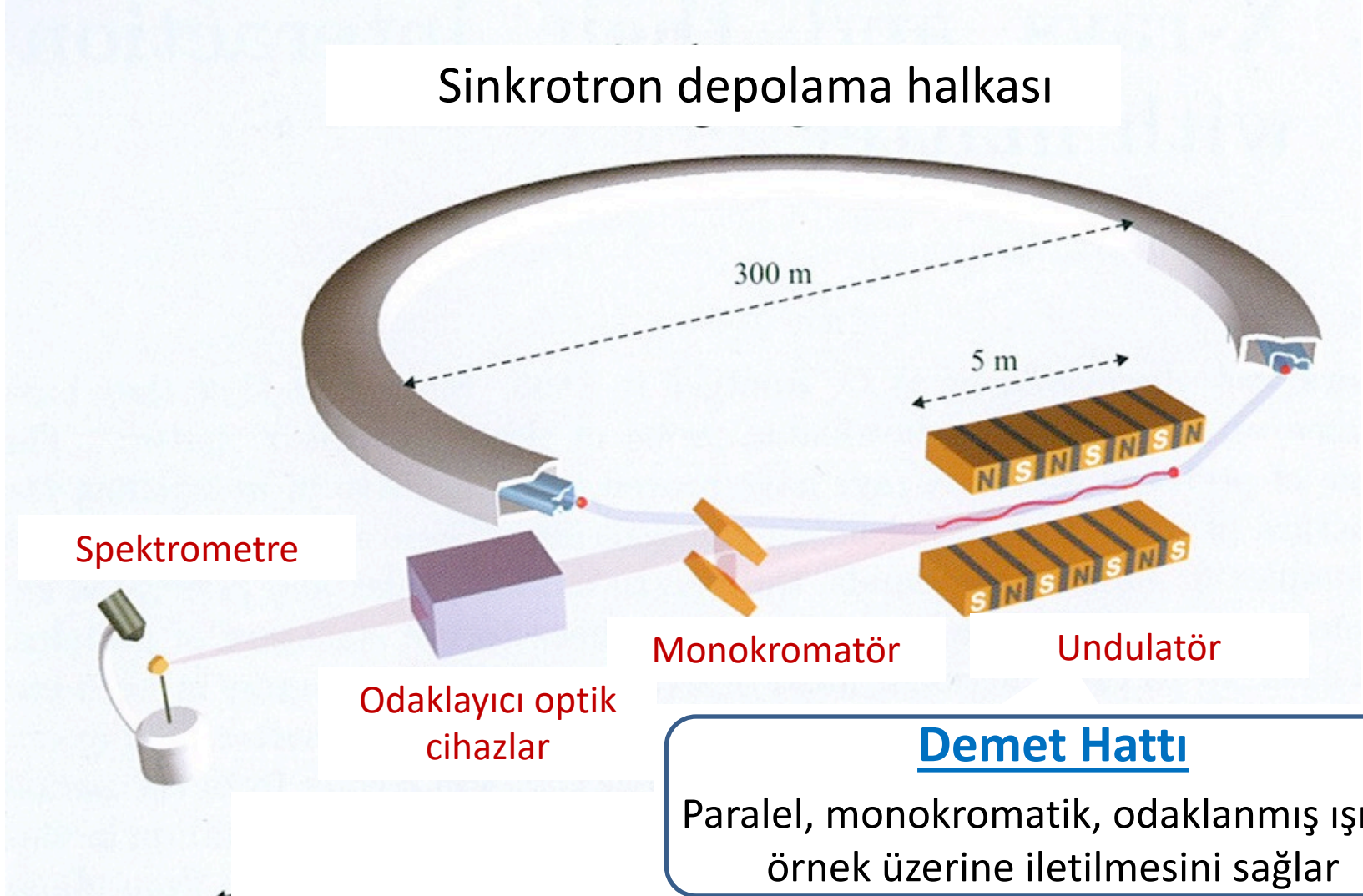
## Dairesel hızlandırıcılarda yüklü parçacıklar:

- RF (RadyoFrekans) kaviteler tarafından sağlanan elektrik alan yardımıyla hızlandırılır.
- Dipol magnetler tarafından sağlanan manyetik alanlar yardımıyla dairesel yörüngede hareket etmeleri sağlanır.
- Insertion Devices (Wiggler, Undulator) tarafından sağlanan periyodik manyetik alanlar yardımıyla yüksek parlaklıkta sinkrotron ışınımı elde edilir.
- Manyetik alan parçacık enerjisine etki etmez, manyetik kuvvetler iş yapmaz

$$\vec{F} = q\vec{E} + q\vec{v} \times \vec{B}$$

*Electric force*                      *Magnetic force*

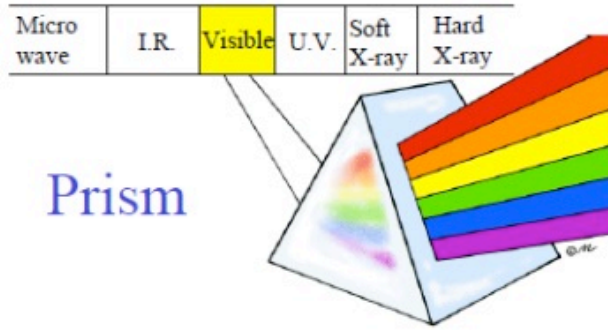
# Sinkrotron Demet Hattı



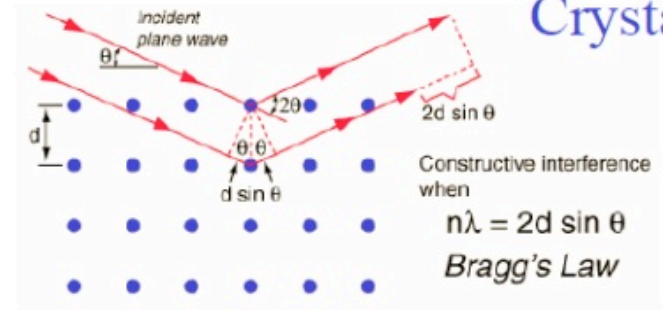
## 15. ULUSAL PARÇACIK HIZLANDIRICILARI ve DEDEKTÖRLERİ YAZ OKULU (UPHDYO-XV)



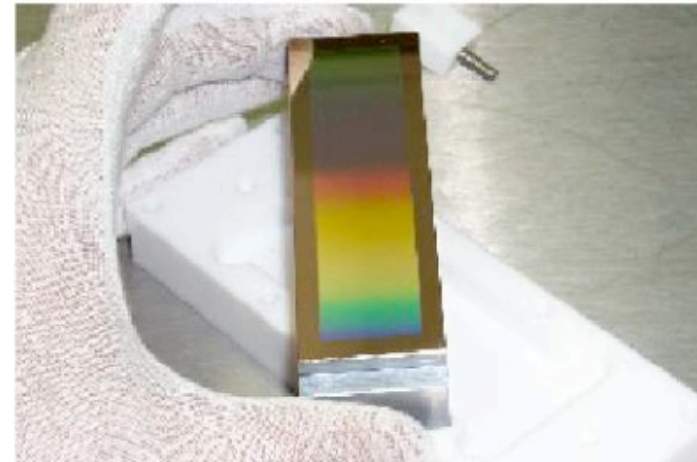
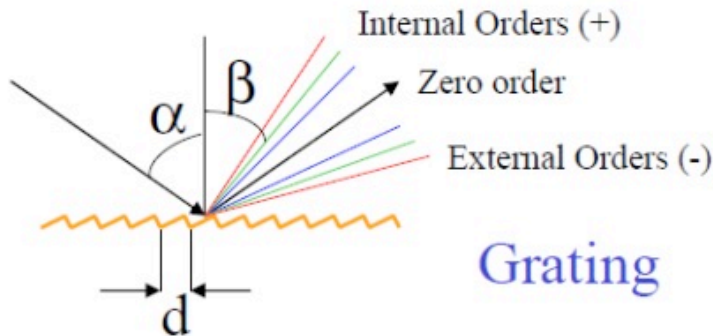
# Monochromators



Micro wave	I.R.	Visible	U.V.	Soft X-ray	Hard X-ray
------------	------	---------	------	------------	------------

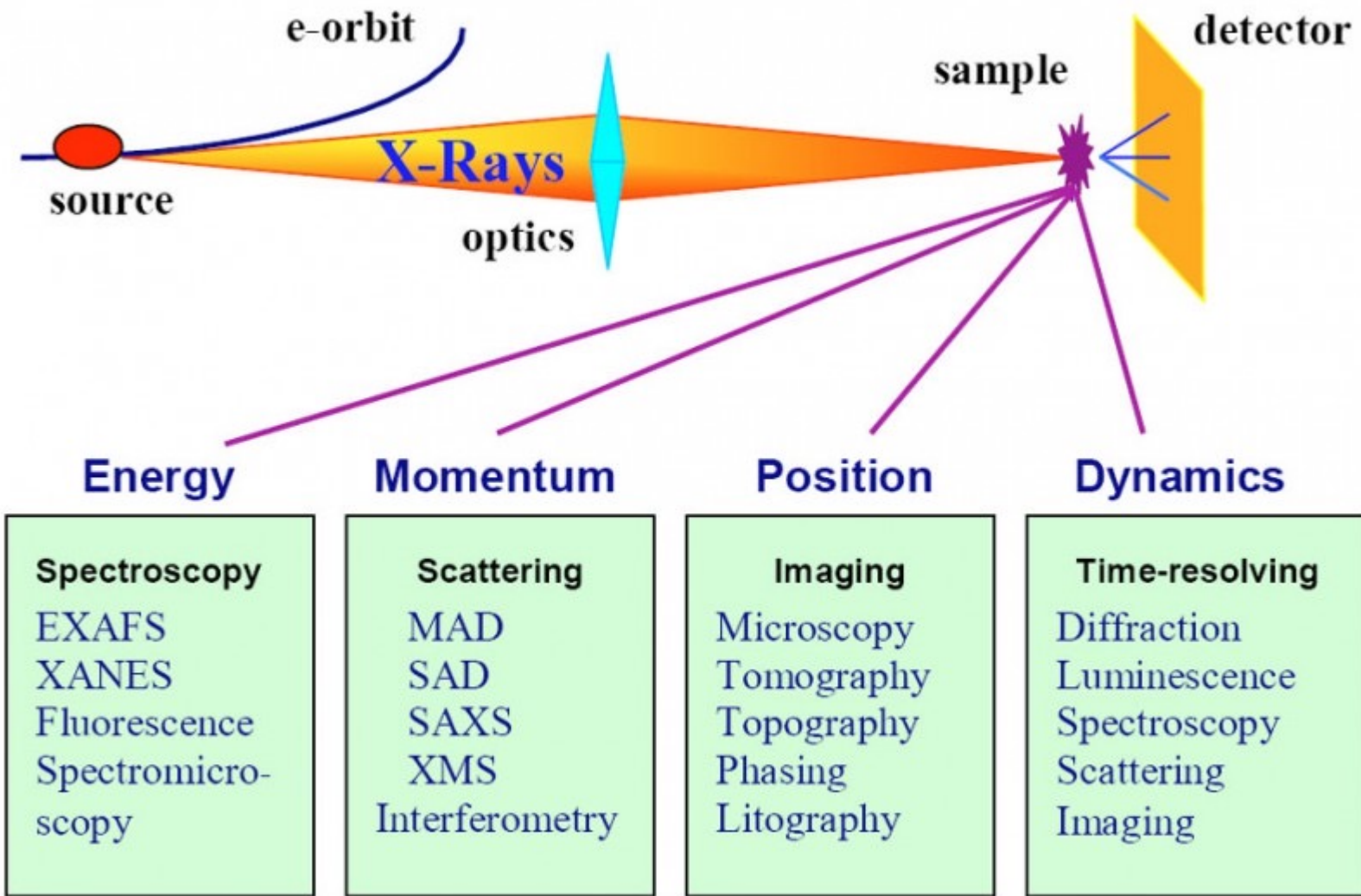


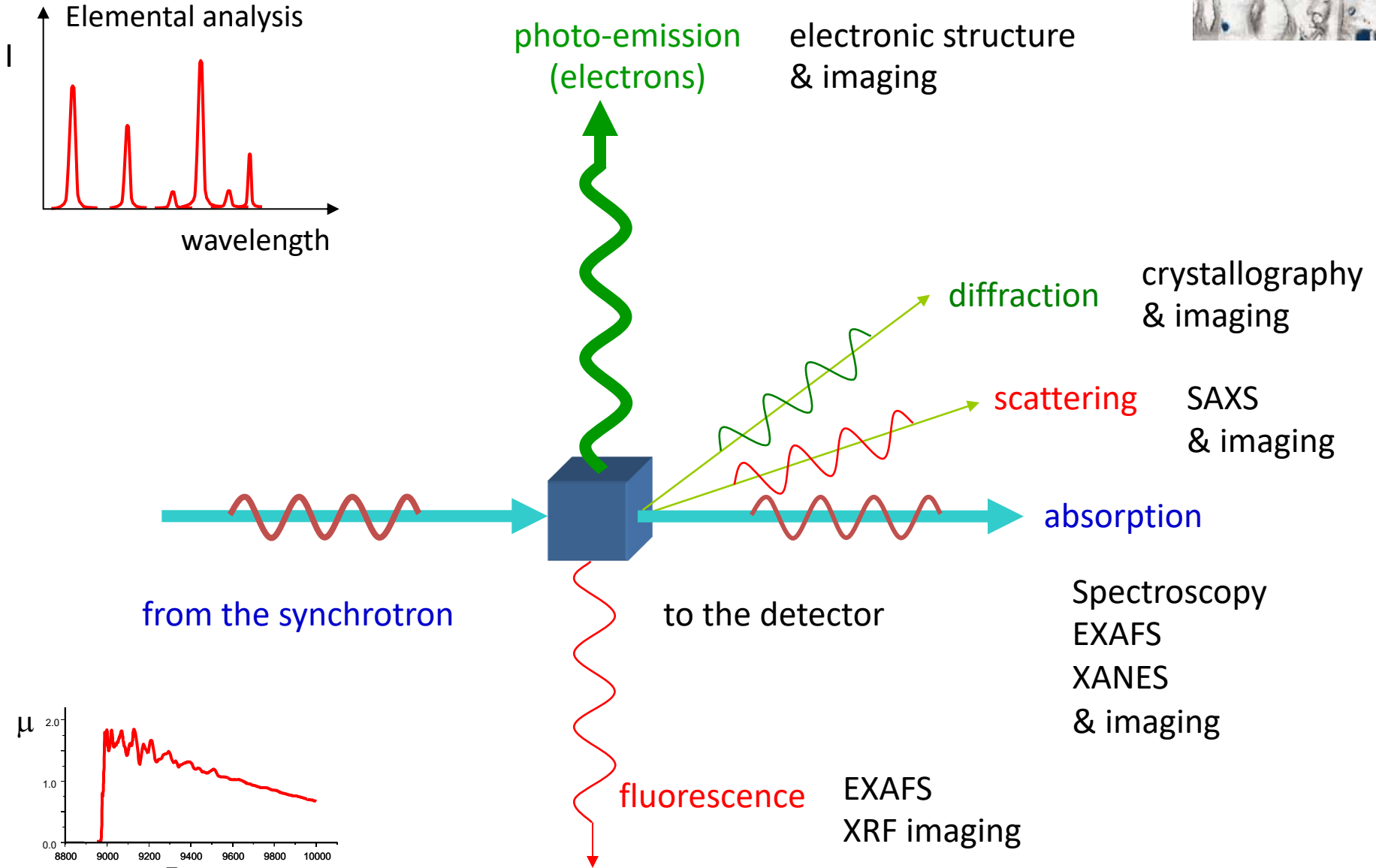
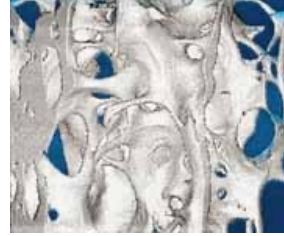
Micro wave	I.R.	Visible	U.V.	Soft X-ray	Hard X-ray
------------	------	---------	------	------------	------------



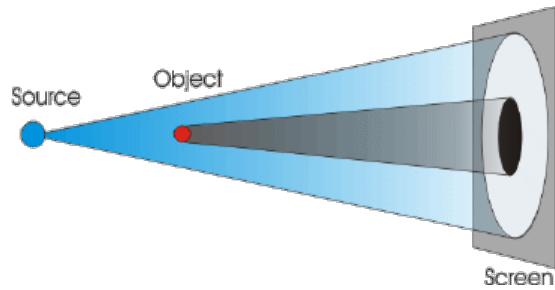


# Deneysel Teknikler

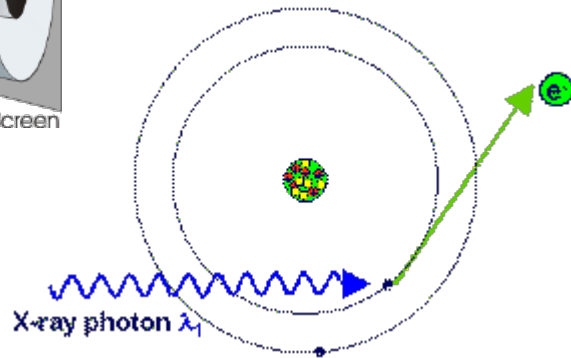




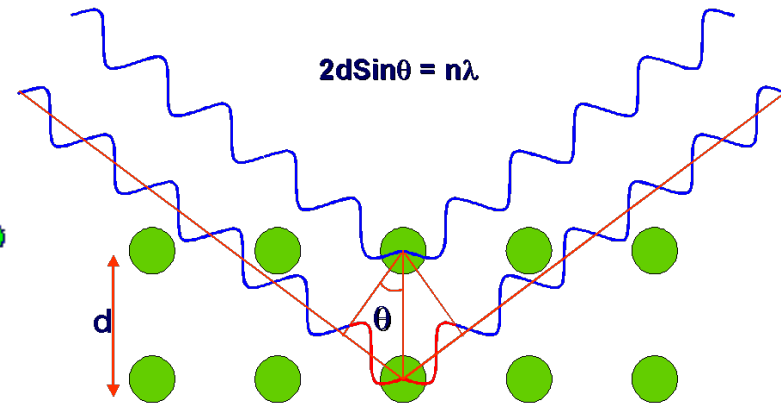
# Interaction of photon's with matter



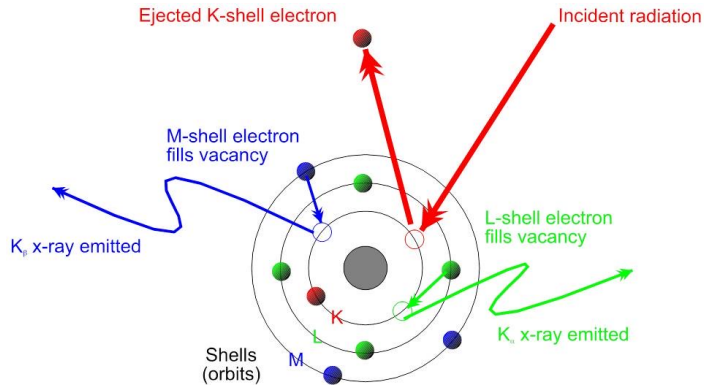
**Radiography**



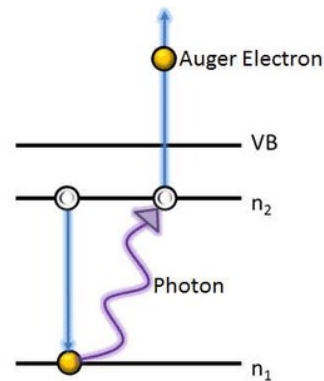
**Photoelectric Effect**



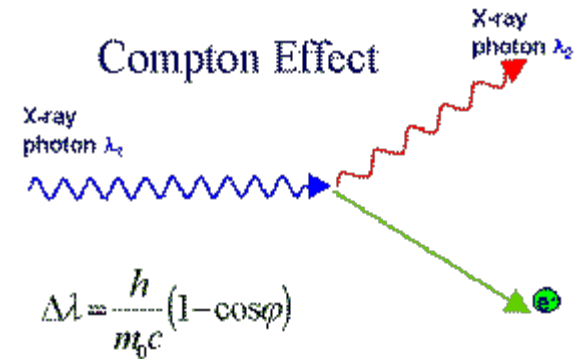
**Bragg Diffraction**



**X-ray Fluorescence Emission**



(c)



$$\Delta\lambda = \frac{h}{m_0c} (1 - \cos\phi)$$

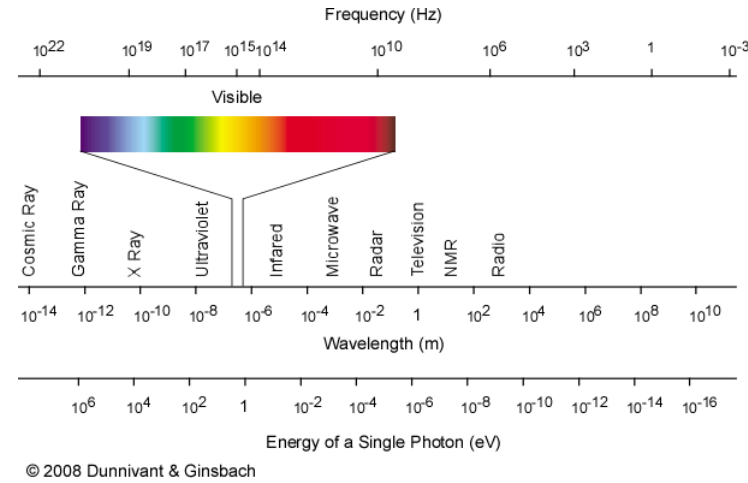
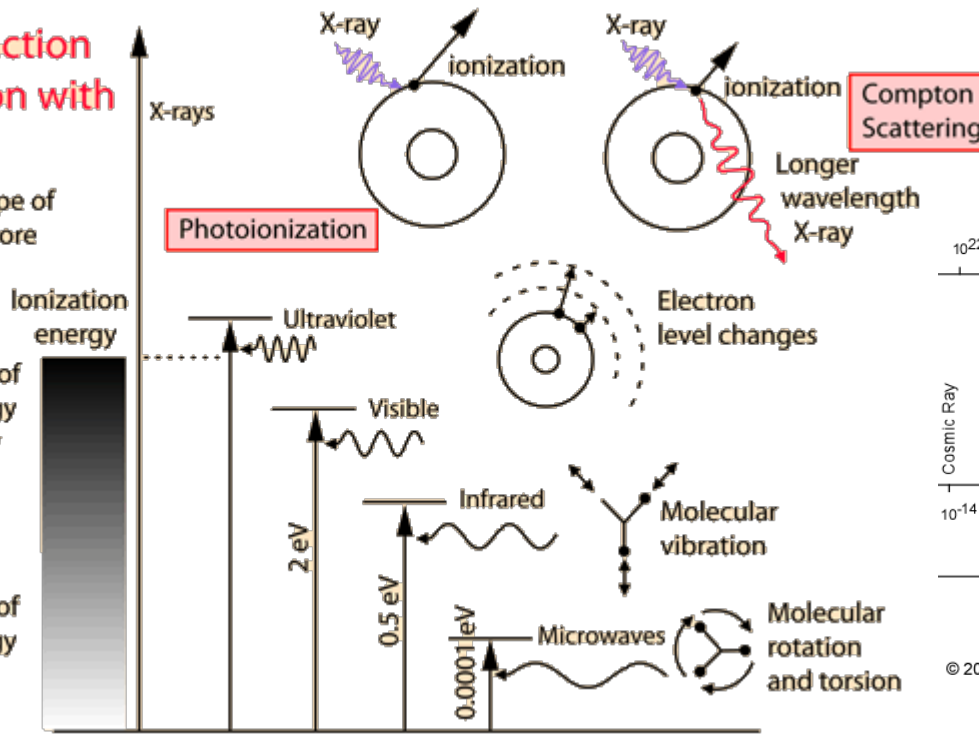
**Compton Scattering**

# The interaction of radiation with matter.

Click on any type of radiation for more information.

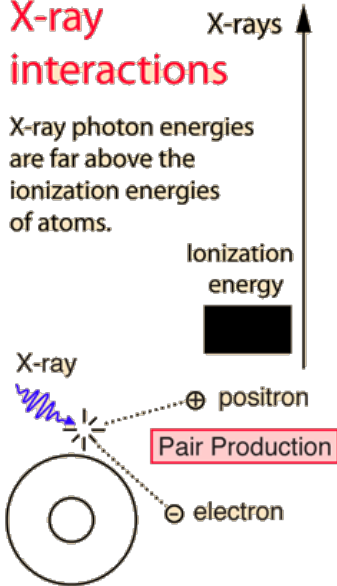
Large number of available energy states, strongly absorbed.

Small number of available energy states, almost transparent.



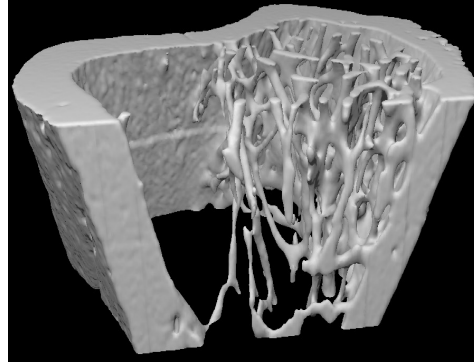
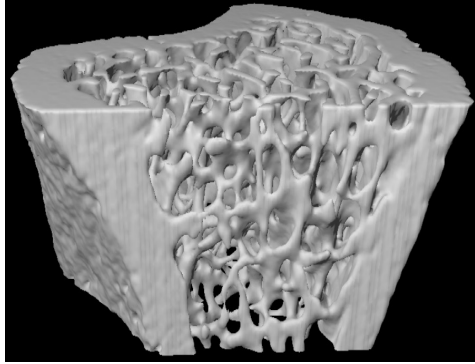
## X-ray interactions

X-ray photon energies are far above the ionization energies of atoms.



- X-ışınları iyonlaştırıcı radyasyon olarak sınıflandırılır Bu, enerjinin tamamını bir elektrona vererek (fotoiyonizasyon) veya enerjinin bir kısmını elektrona ve geri kalanını daha düşük enerjili bir fotona vererek (Compton saçılması) meydana gelebilir. Yeterince yüksek enerjilerde, X-ışını fotonu bir elektron-pozitron çifti oluşturabilir.

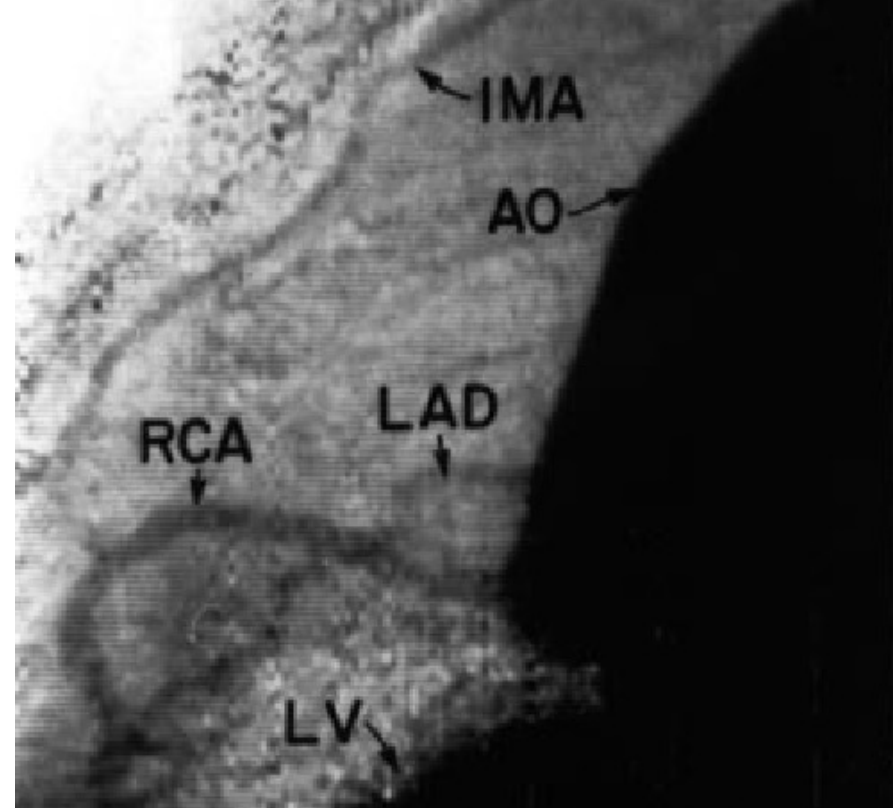
# TIP



Östrojen kaybından  
önce

Östrojen kaybından  
sonra

Osteoporoz (kemik dokusunun içinde anormal derecede boşuk oluşumu)

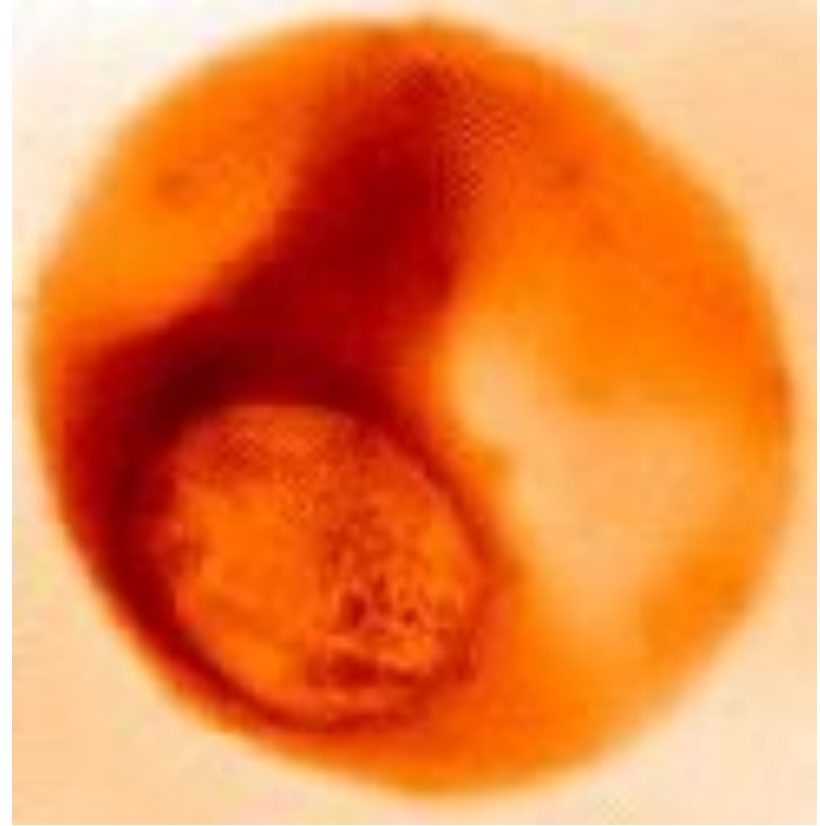


Koroner atardamarının sinkrotron ışınımı kullanılarak alınan görüntüsü (SSRL, 1986)

## Hücresel Boyutta Görüntüleme

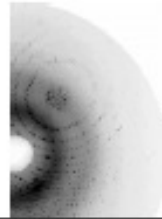
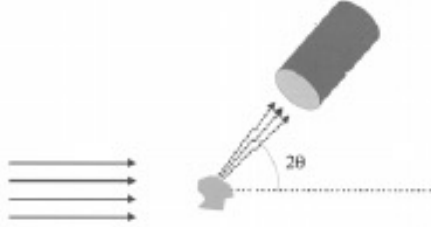
Sıtma mikrobu tarafından enfeksiyona uğramış kan hücresinin kan damarlarına tutunmasının nedeninin araştırılması

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

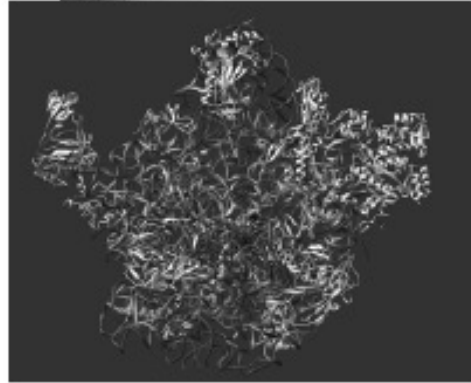


# Protein Kristalografisi

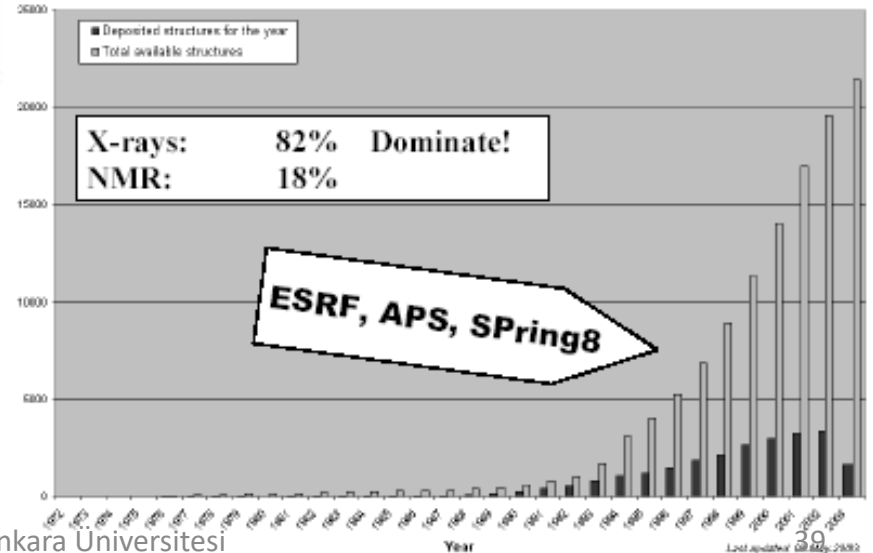
Protein structure



Diffraction pattern

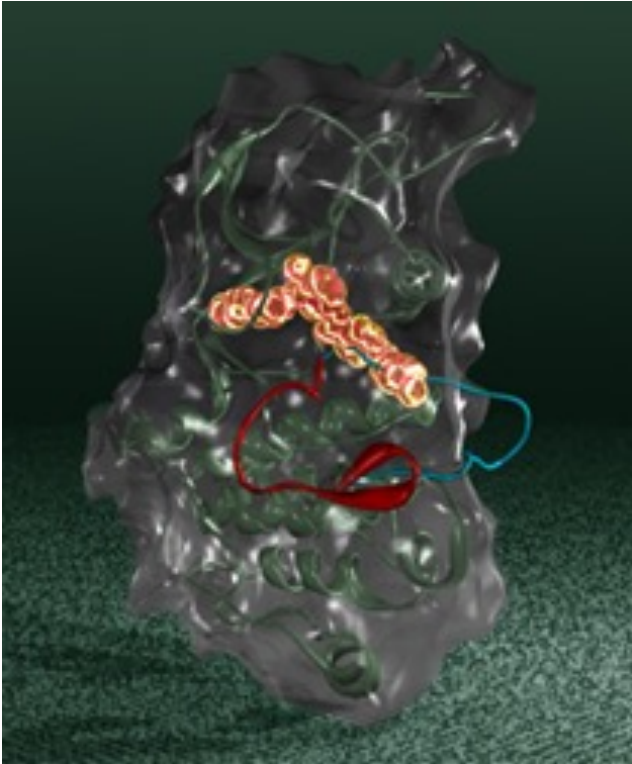


## Protein Data Bank



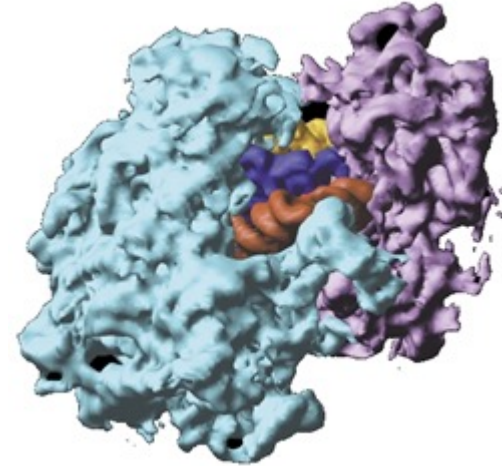
Genetik bozukluklar ile ilgili bilgiye sahip olmak ve bunların tedavisi için gerekli ilaçların üretiminde herbir proteinin detaylı yapısını araştırmamız gerekir

İlaç tasarımı  
GLEEVEC



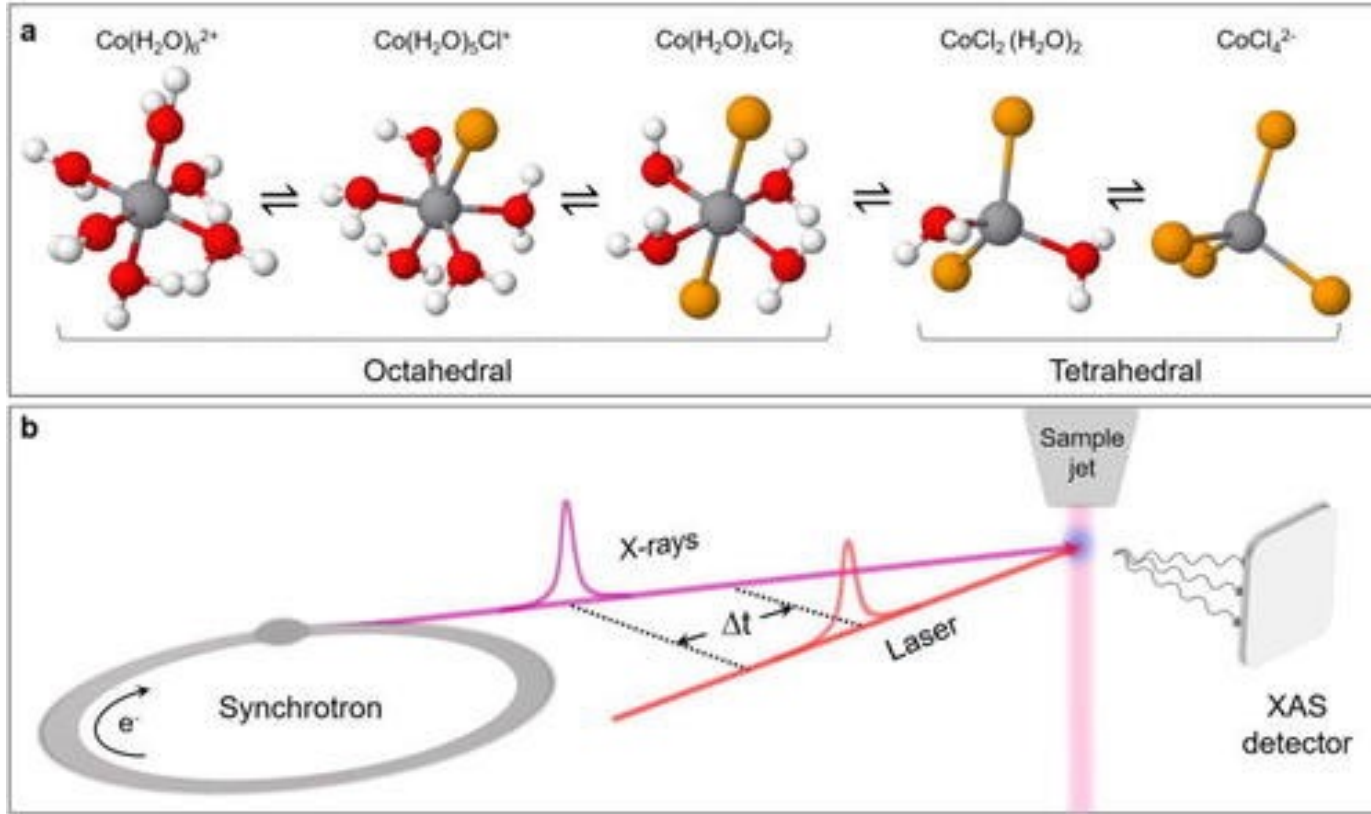
Lösemi

Proteinlerin nasıl oluştuğunun  
anlaşılması





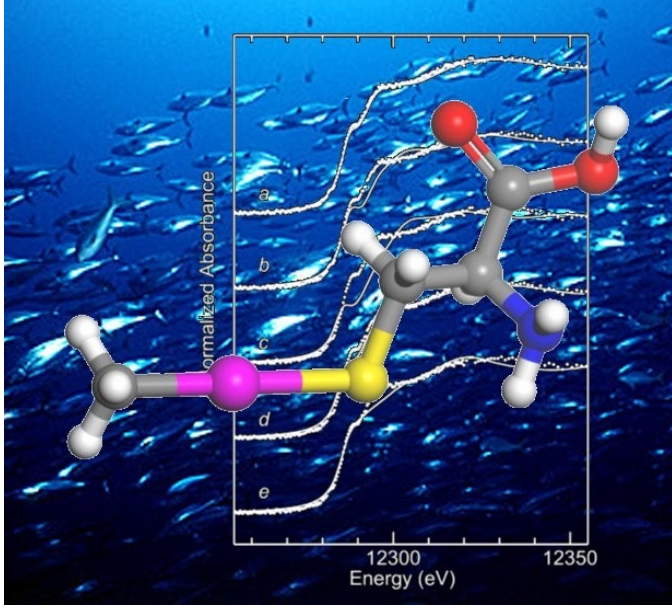
# Moleküler yapıdaki değişimler: Pump-Probe deneyleri



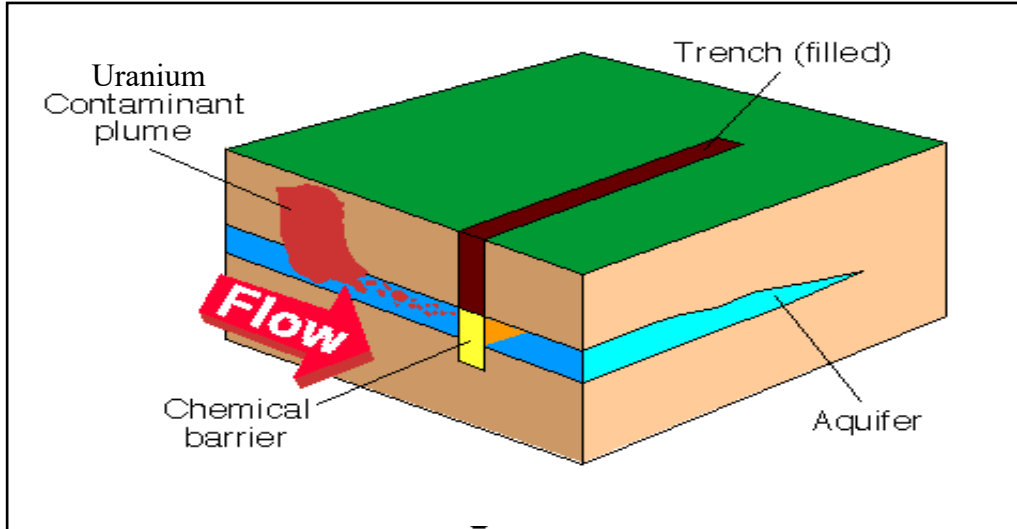
Pump: Laser

Probe: Synchrotron radiation

# KİMYA & ÇEVRE BİLİMİ

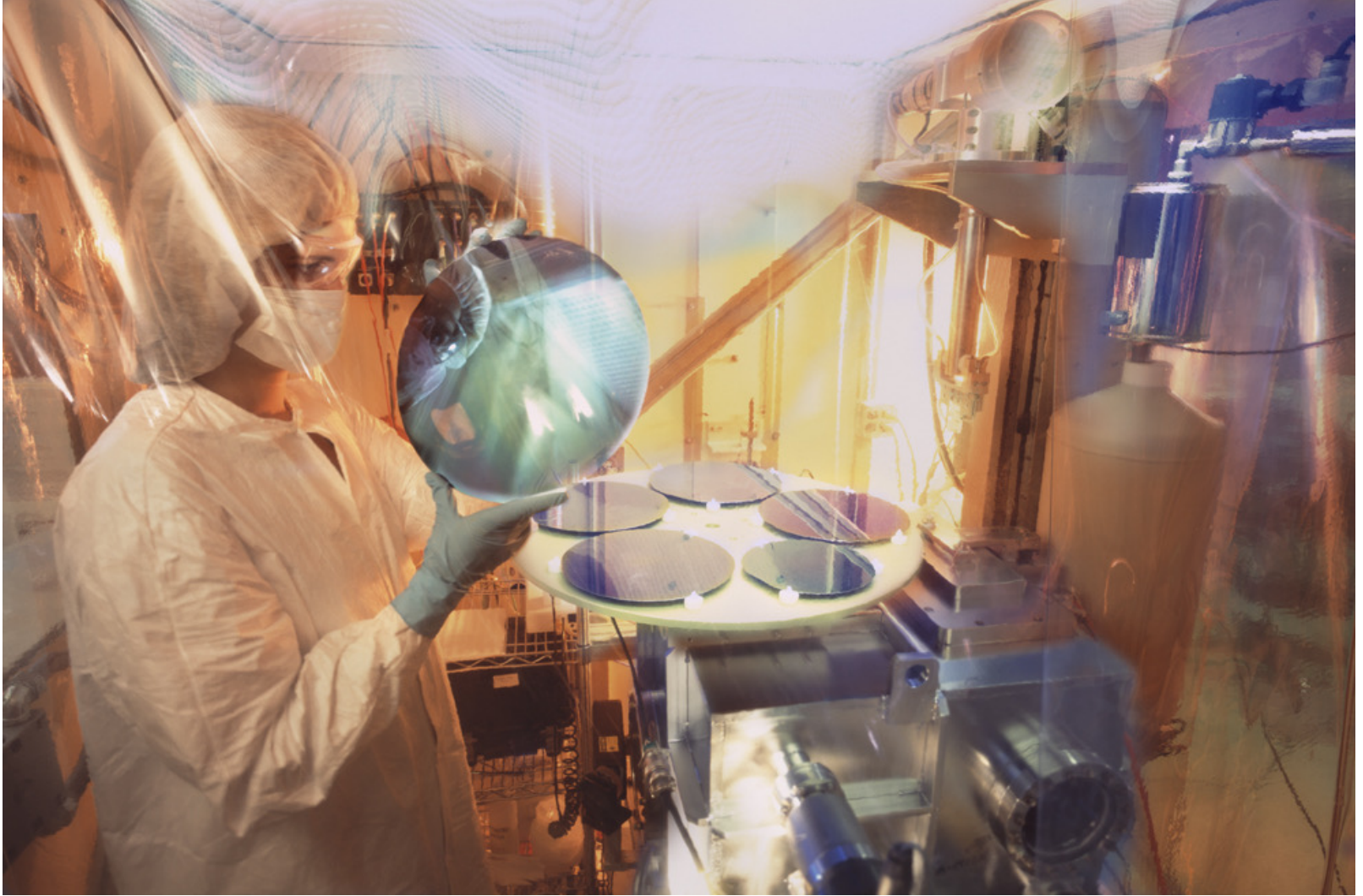


Balıkta bulunan çok düşük seviyedeki civanın ölçümü ve kimyasal formunun belirlenmesi

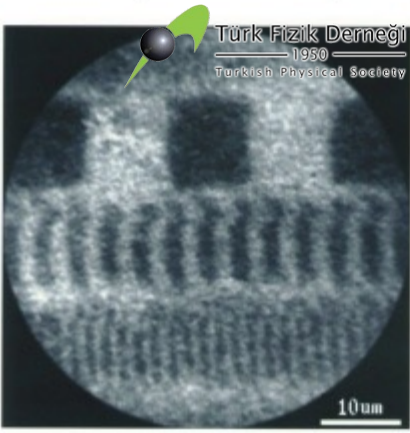


Su kaynaklarını tehdit eden toksik ve radyoaktif atıkların SR yolu ile anlaşılması (SSRL)

# MALZEME BİLİMİ

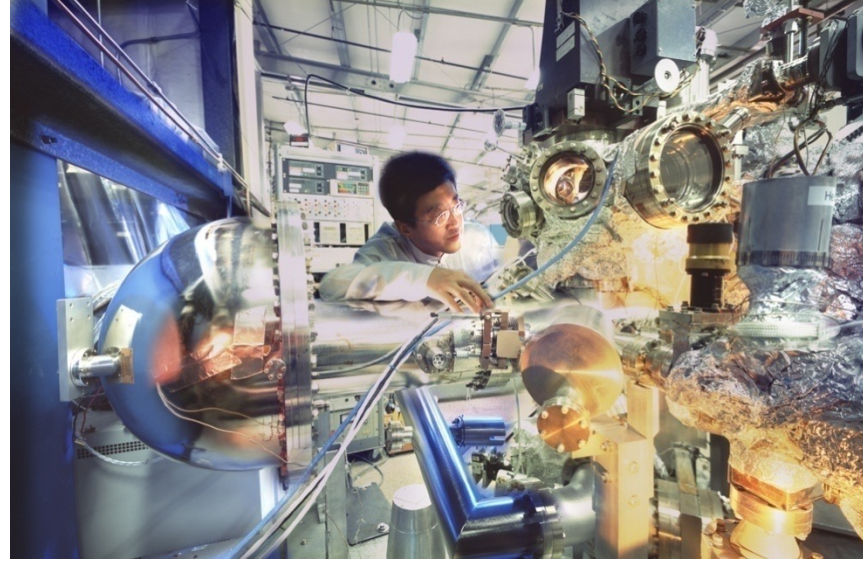


Bilgisayar çiplerinde sorunlara yol açan silikon yüzeylerdeki kirlenme seviyesinin SR kullanılarak incelenmesi



Bilgisayarın hard diskindeki magnetik çiplerin görüntülenmesi

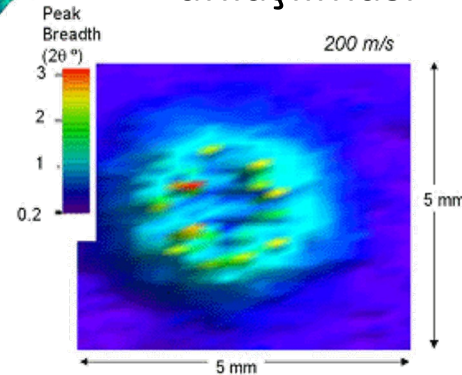
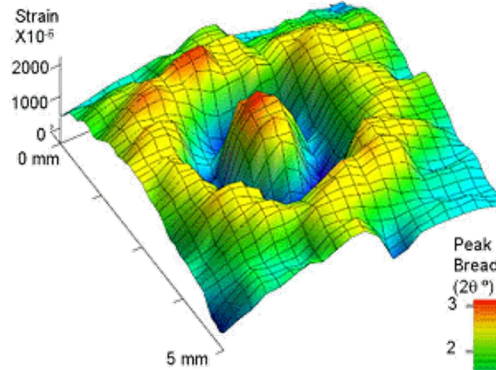
## 15. ULUSAL PARÇACIK HIZLANDIRICILARI ve DEDEKTÖRLERİ YAZ OKULU (UPHDYO-XV)



Yüksek sıcaklık süperiletkenlerinin nasıl çalıştığını anlamak için SR kullanımı

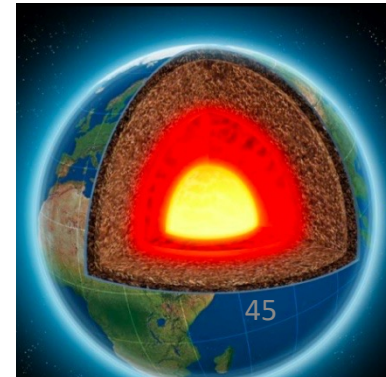
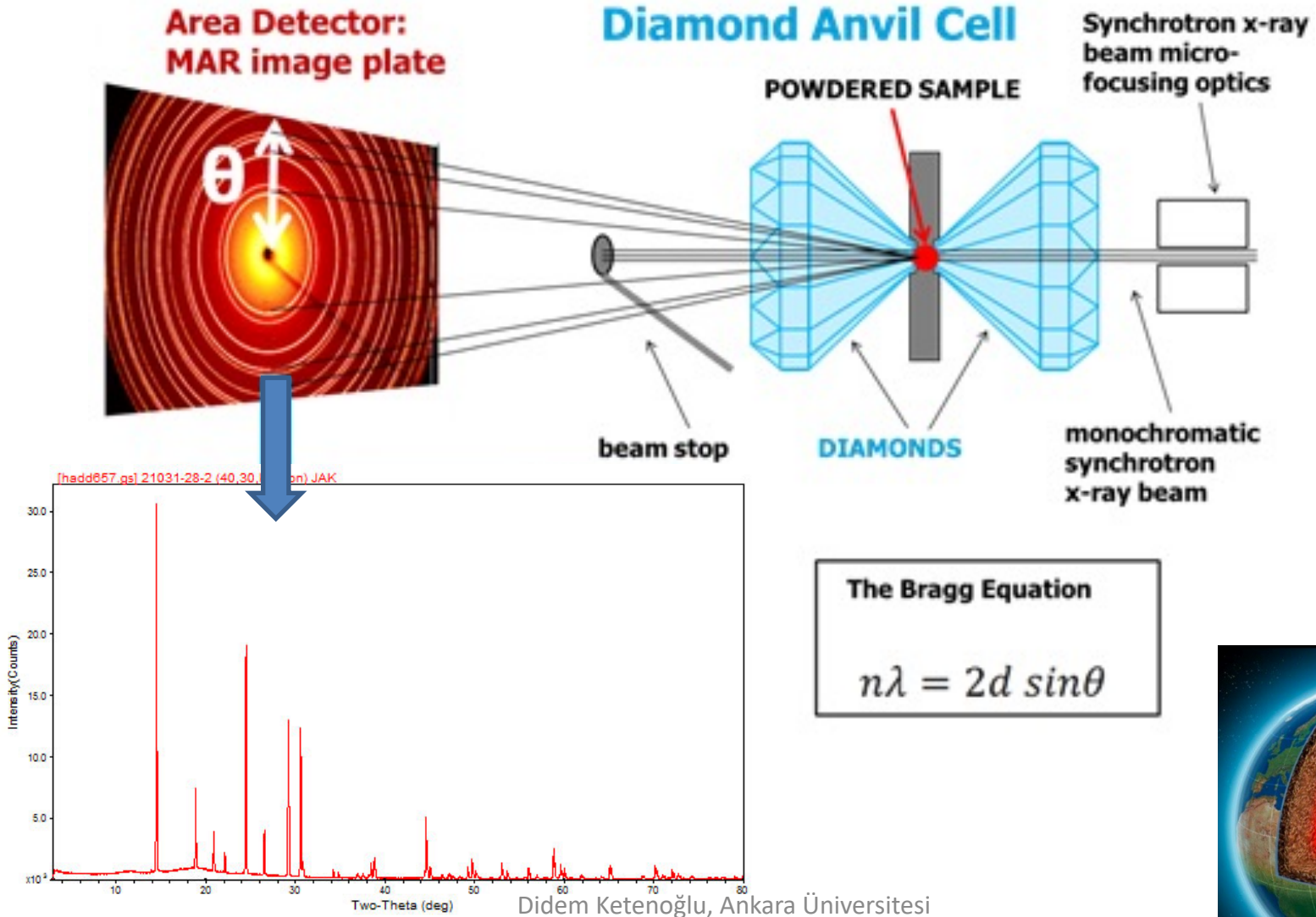


SR kullanarak minyatür mekanik ve elektromekanik aygıtların yapımı



Uçak türbinlerine yabancı maddelerin nasıl zarar verdiği SR yolu ile anlaşılması

# JEOLOJİ BİLİMİ



# 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 PALAEOANTHROPOLOGY



*“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
<b>PETRA-III, DESY</b>	<b>Germany</b>	<b>6</b>	<b>2304</b>	<b>2009</b>
ALBA	Spain	3	270	2010
TPS, Taiwan Photon Source	Taiwan	3	518.4	2015
NSLS-II, National Synchrotron Light Source	US	3	792	2015

APS 7 GeV



ESRF 6 GeV



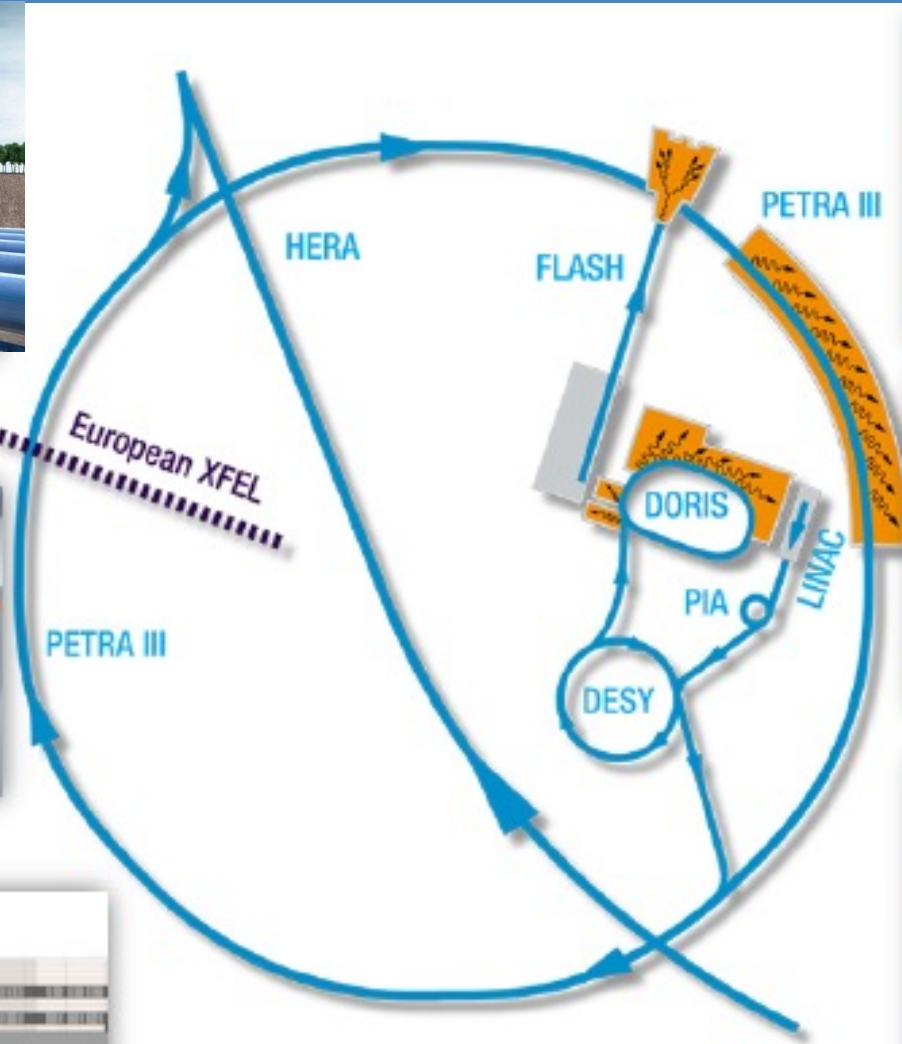
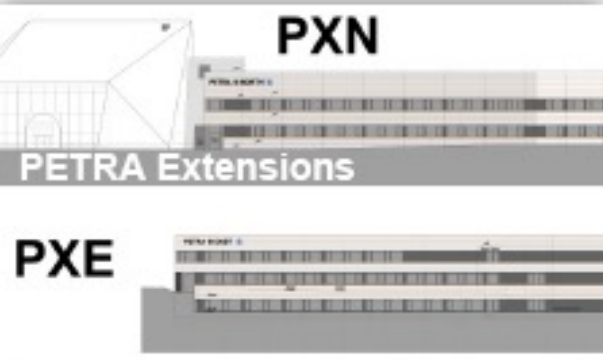
Spring-8 8 GeV



PETRA-III 6 GeV

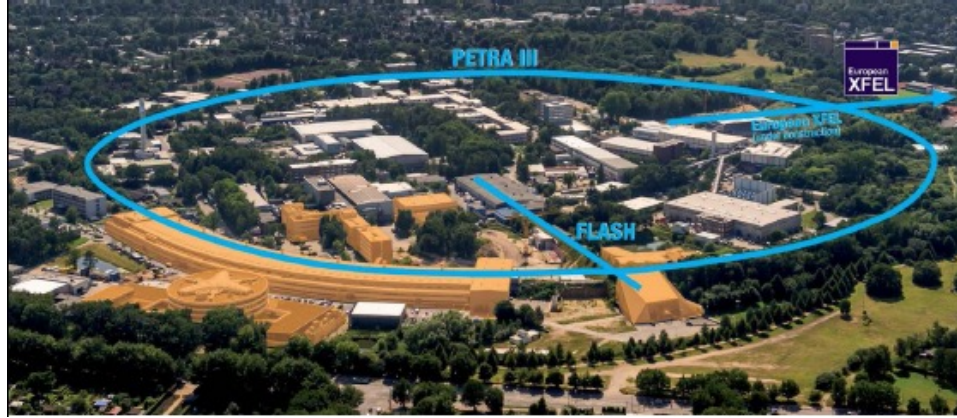


# DESY FOTON KAYNAKLARI

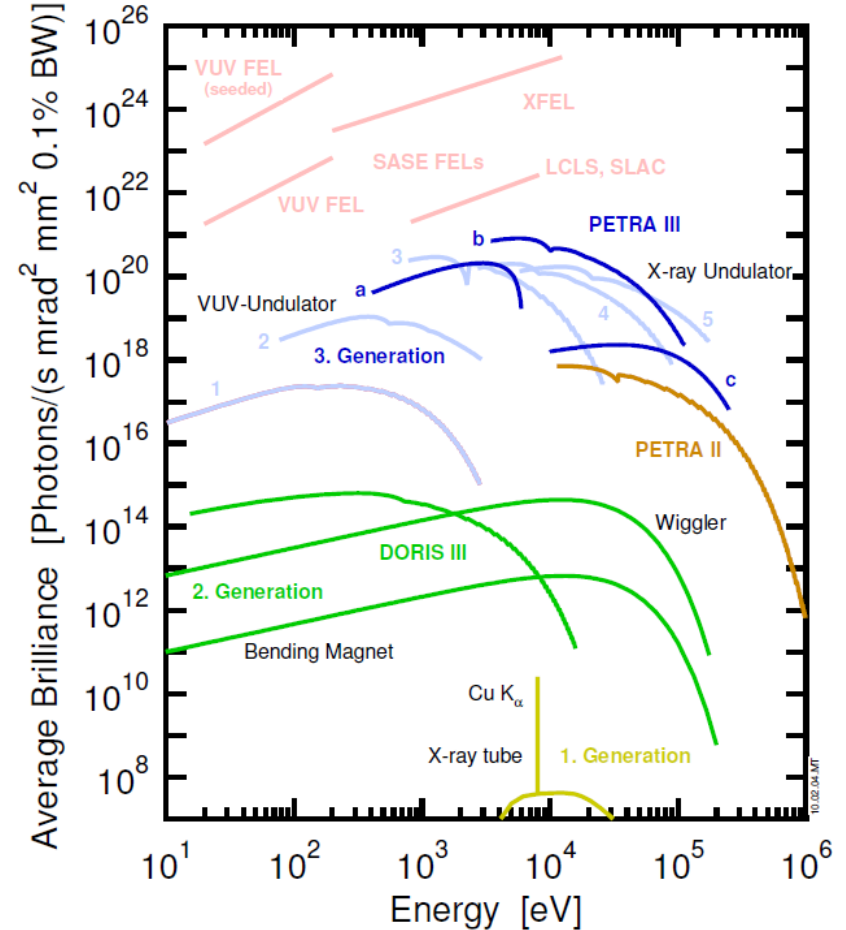


# PETRA III

Dünyanın en parlak sinkrotron ışınım kaynağı



- Elektron enerjisi:** 6 GeV
- Parlaklık:**  $10^{21}$  foton/(s mm<sup>2</sup>mrad<sup>2</sup> 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

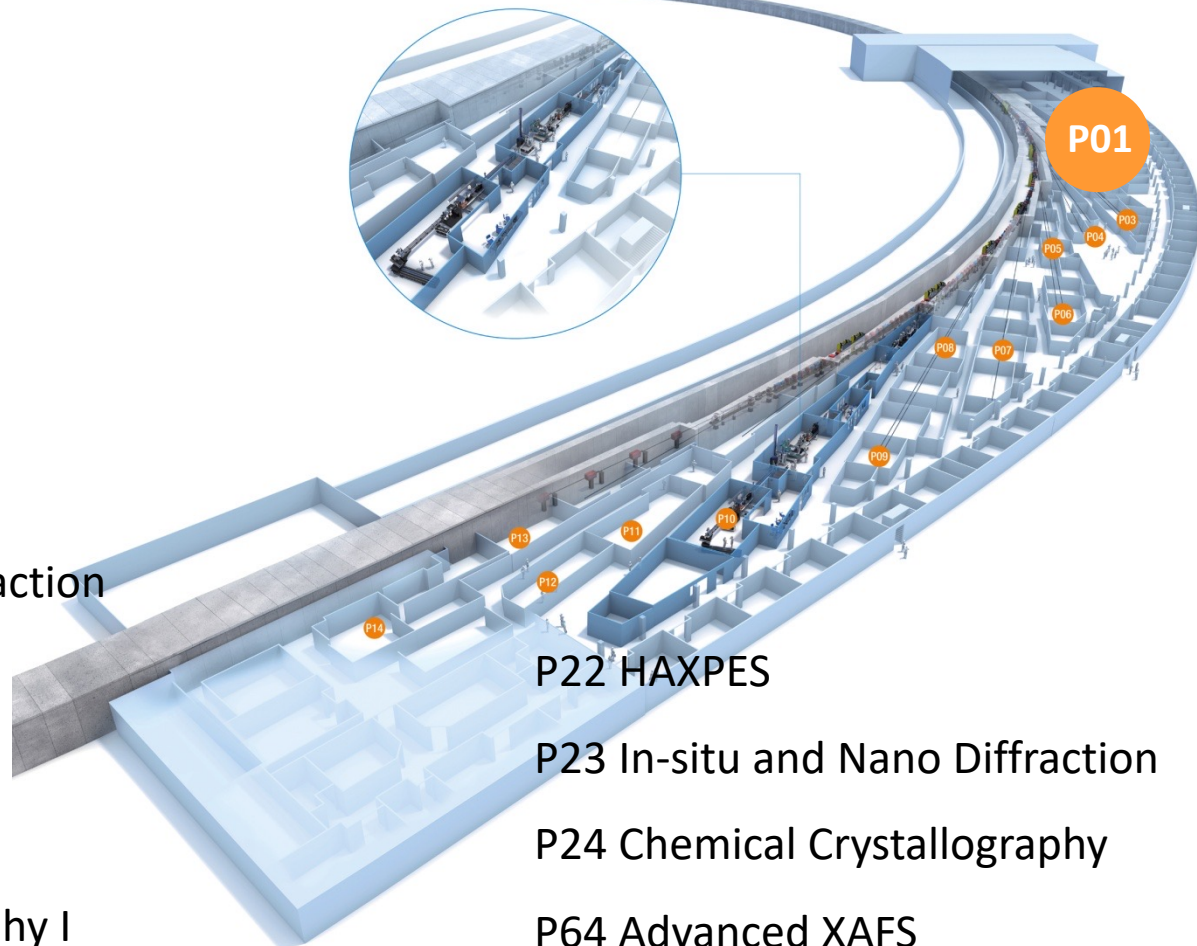
P10 Coherence Applications

P11 Bio-Imaging and Diffraction

P12 BioSAXS

P13 Macromolecular Crystallography I

P14 Macromolecular Crystallography II



P22 HAXPES

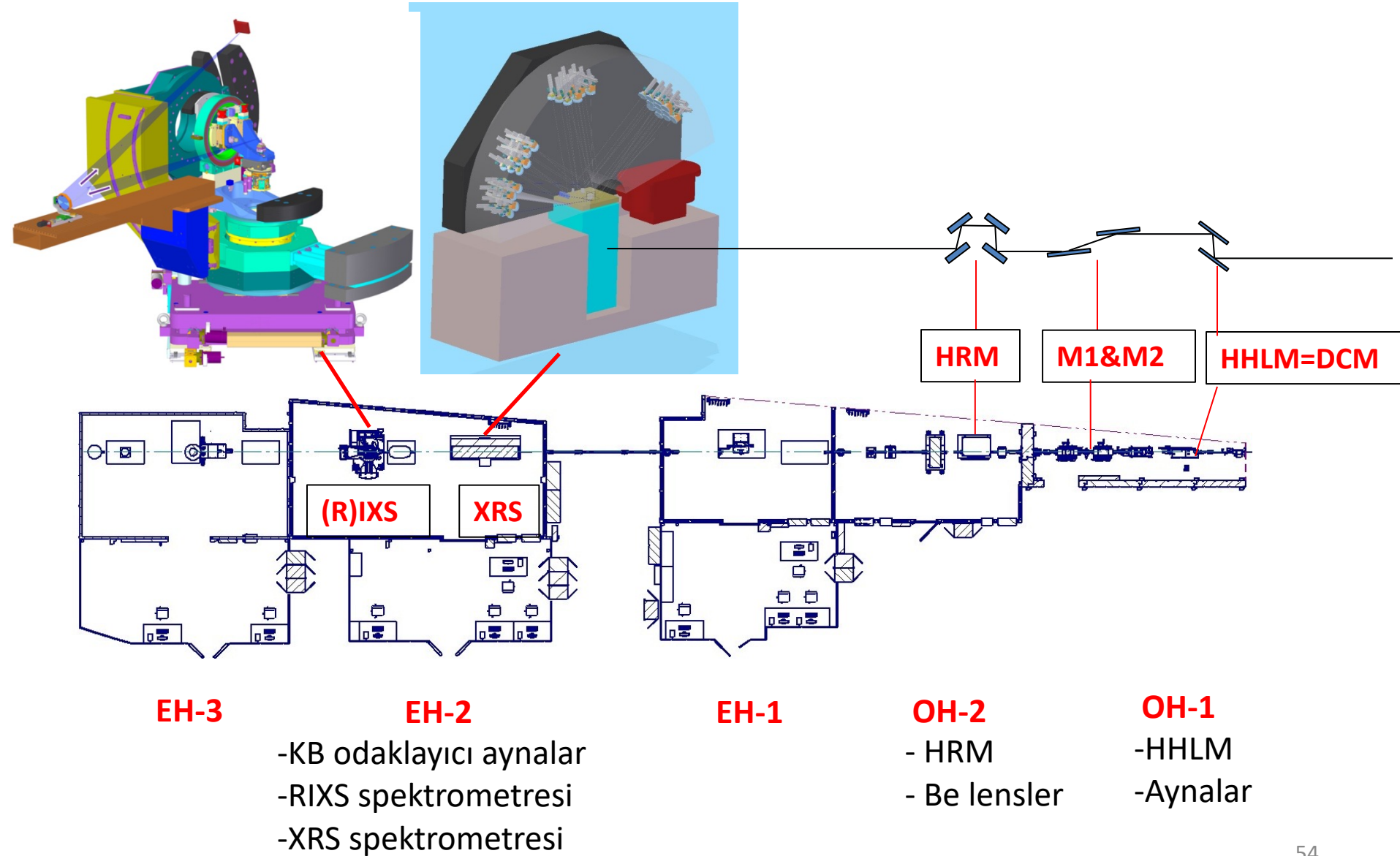
P23 In-situ and Nano Diffraction

P24 Chemical Crystallography

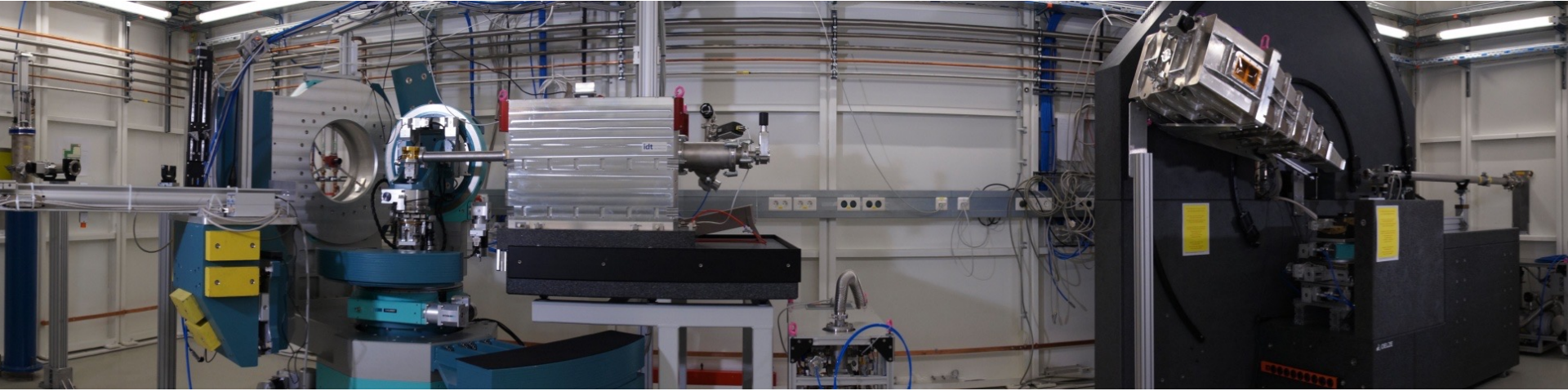
P64 Advanced XAFS

P65 Applied XAFS

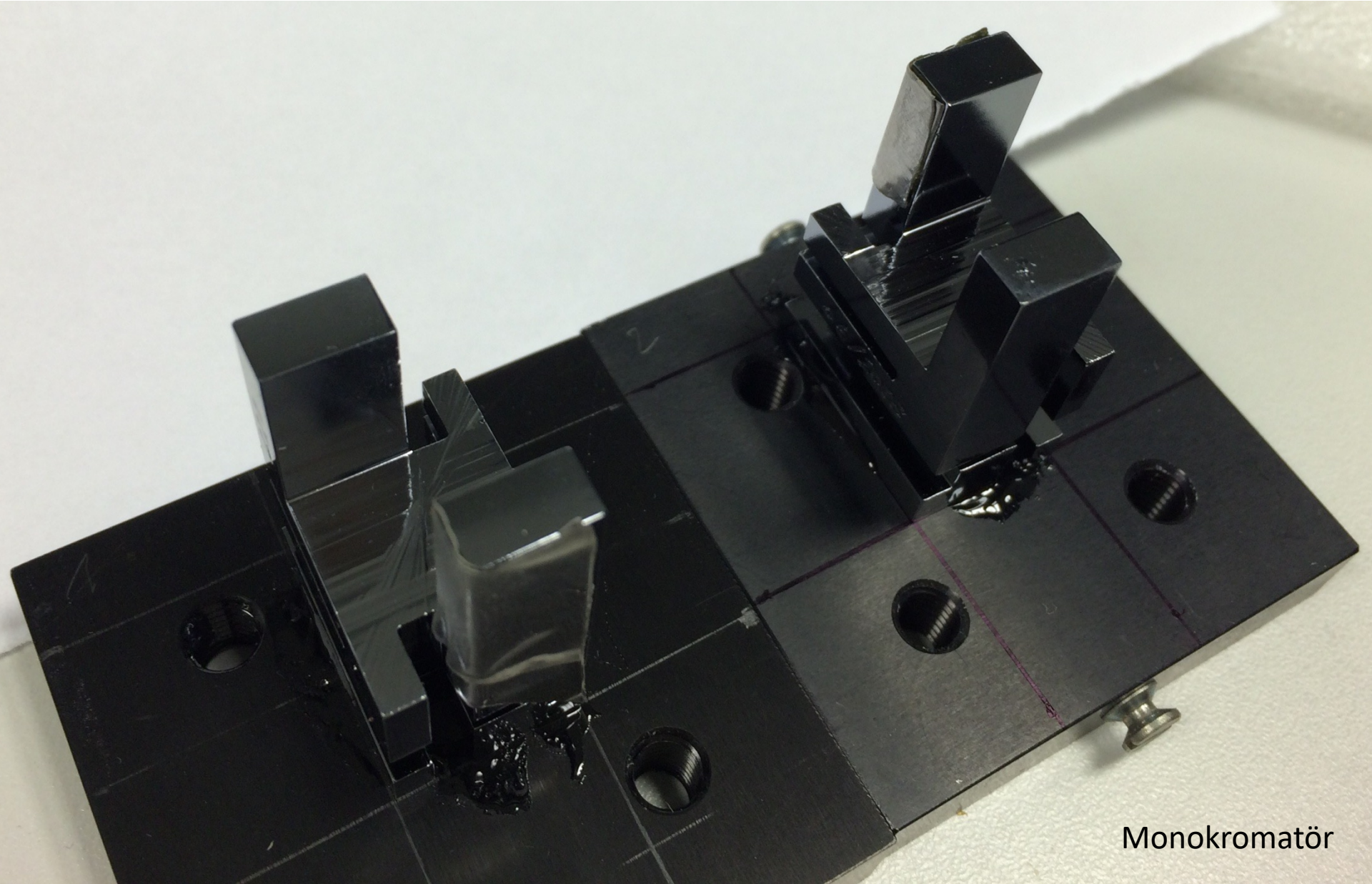
# “P01-HIGH RESOLUTION DYNAMICS” DEMET HATTI



# “P01-HIGH RESOLUTION DYNAMICS” DEMET HATTI



15. ULUSAL PARÇACIK HIZLANDIRICILARI ve DEDEKTÖRLERİ YAZ OKULU (UPHDYO-XV)



Monokromatör



## Focussing with Be lenses and KB mirorr

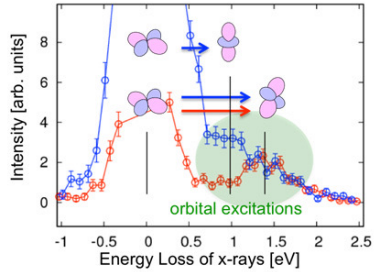


**Compound refractive Be lenses of different radii for moderate foci between 30 and 100 microns.**

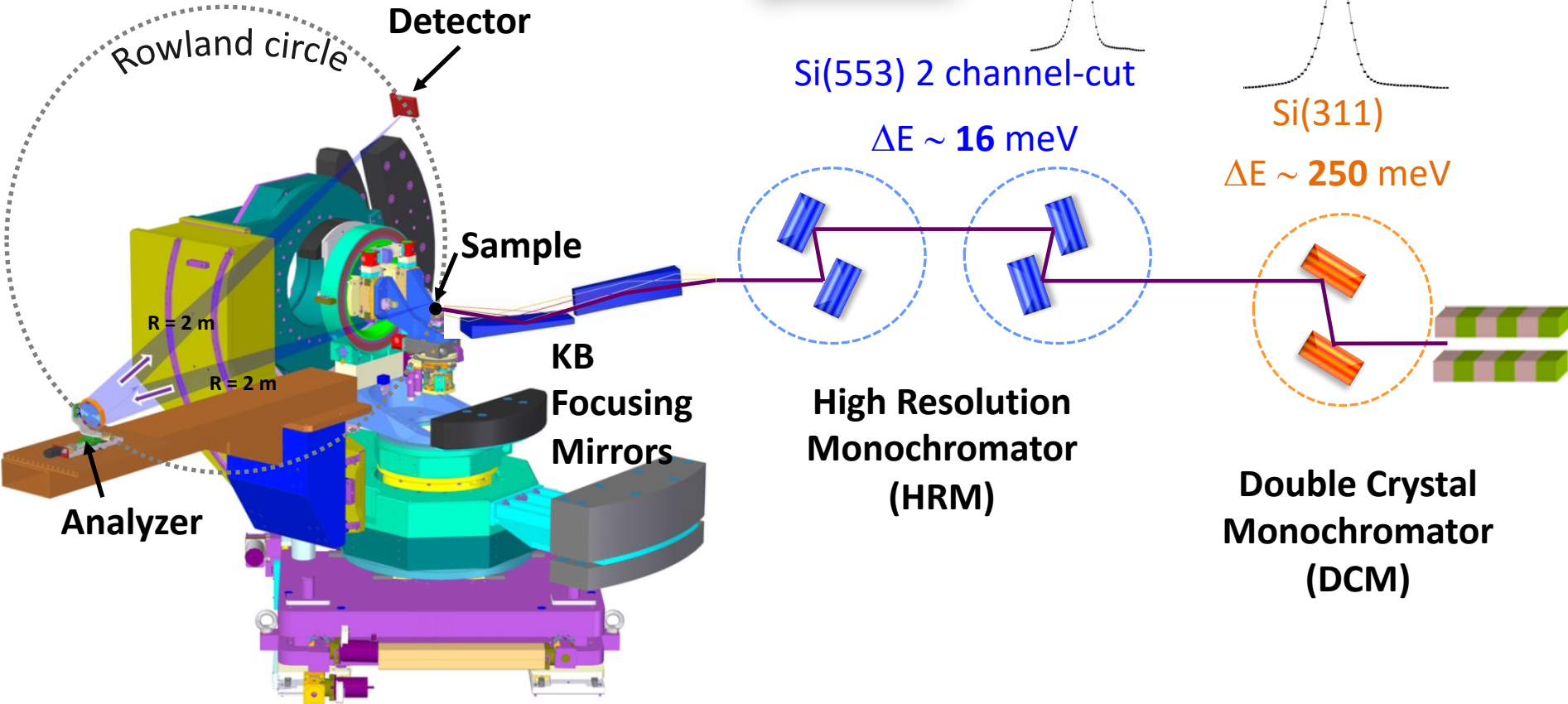
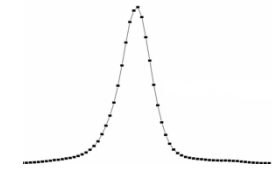
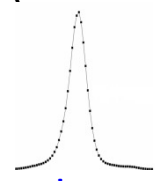


**Kirkpatrick-Baez mirror system for 5 x 9  $\mu\text{m}^2$  focussing**

# Deneysel Düzenek I: Rezonans Elastik Olmayan X-ışını Saçılma (RIXS) Spektroskopisi

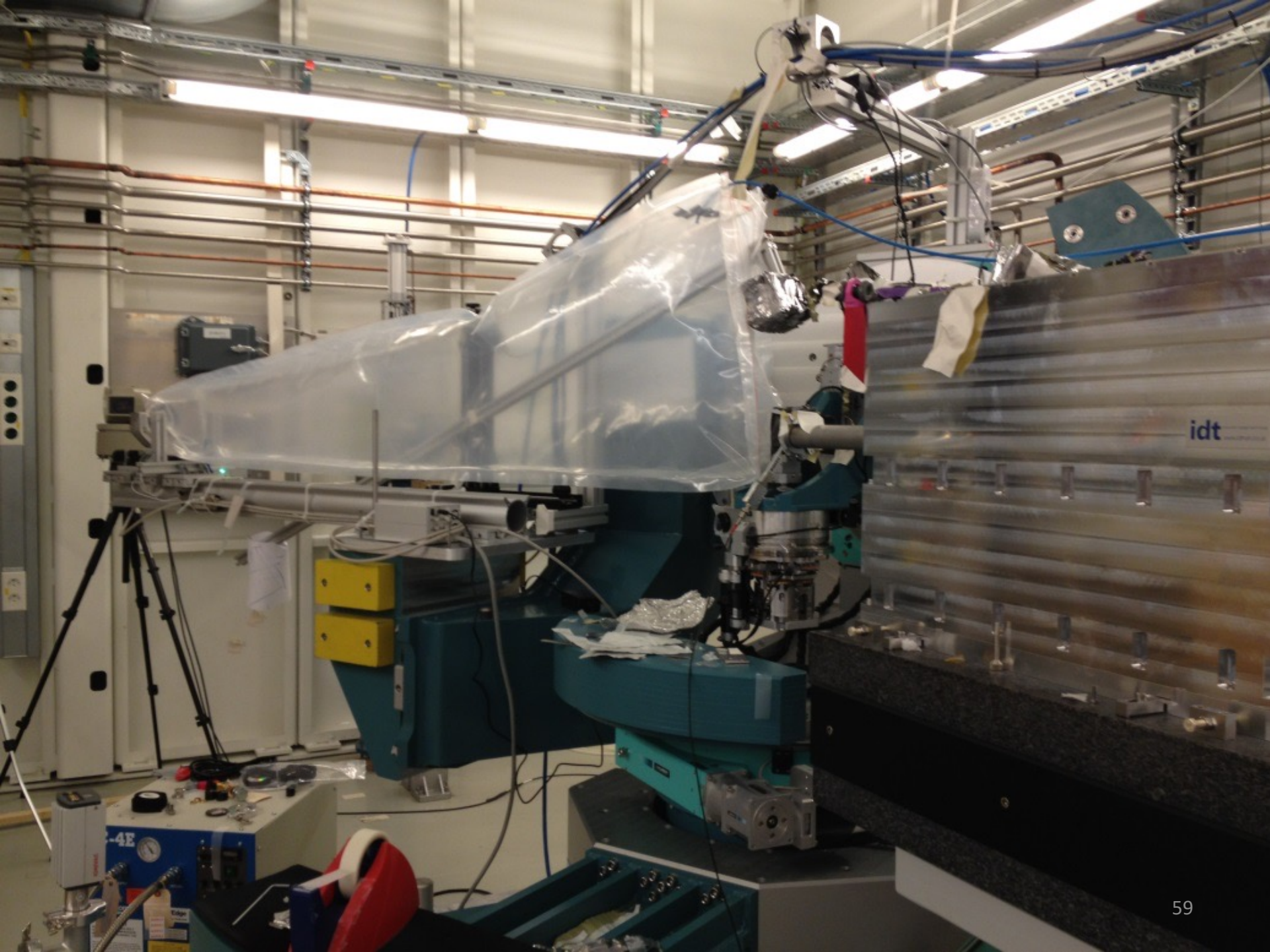


Incident energy = 8981 eV (Cu K-edge)



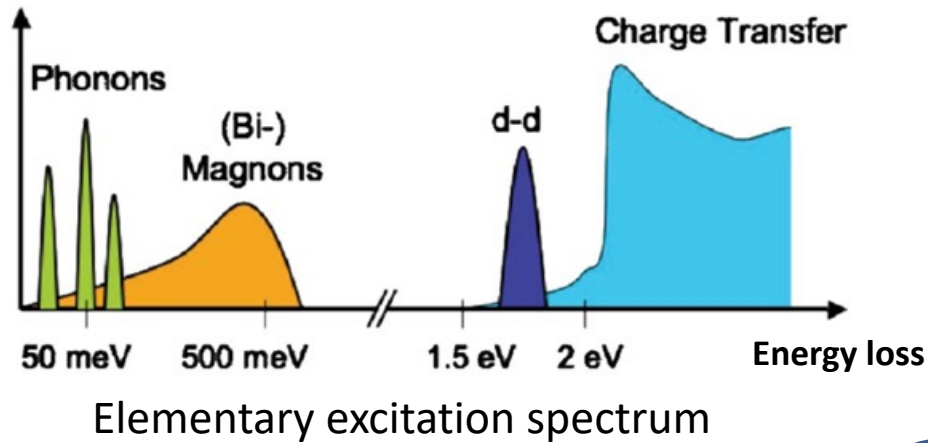
Incident flux on the sample  $\sim 6 \times 10^{10}$  photons/s/100mA

Beamsize: 9(H) $\times$ 3(V)  $\mu\text{m}^2$

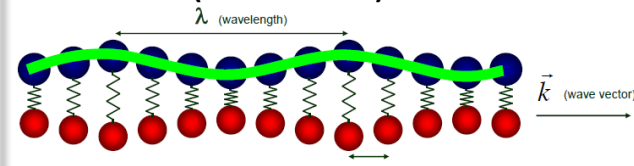


# RIXS: Düşük Enerjili Uyarılmaların Ölçümü

Düşük enerjili uyarılmaların momentum transferine bağlı ölçümü

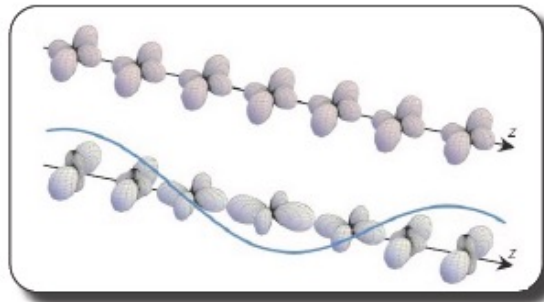


Lattice vibrations  
(Phonons)

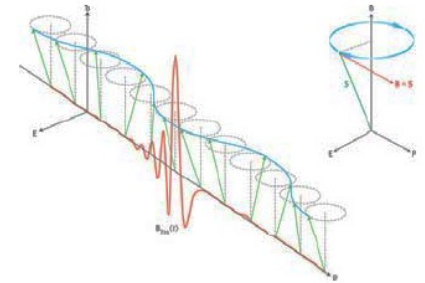


collective excitation of atoms or molecules in a crystal structure

Orbitons

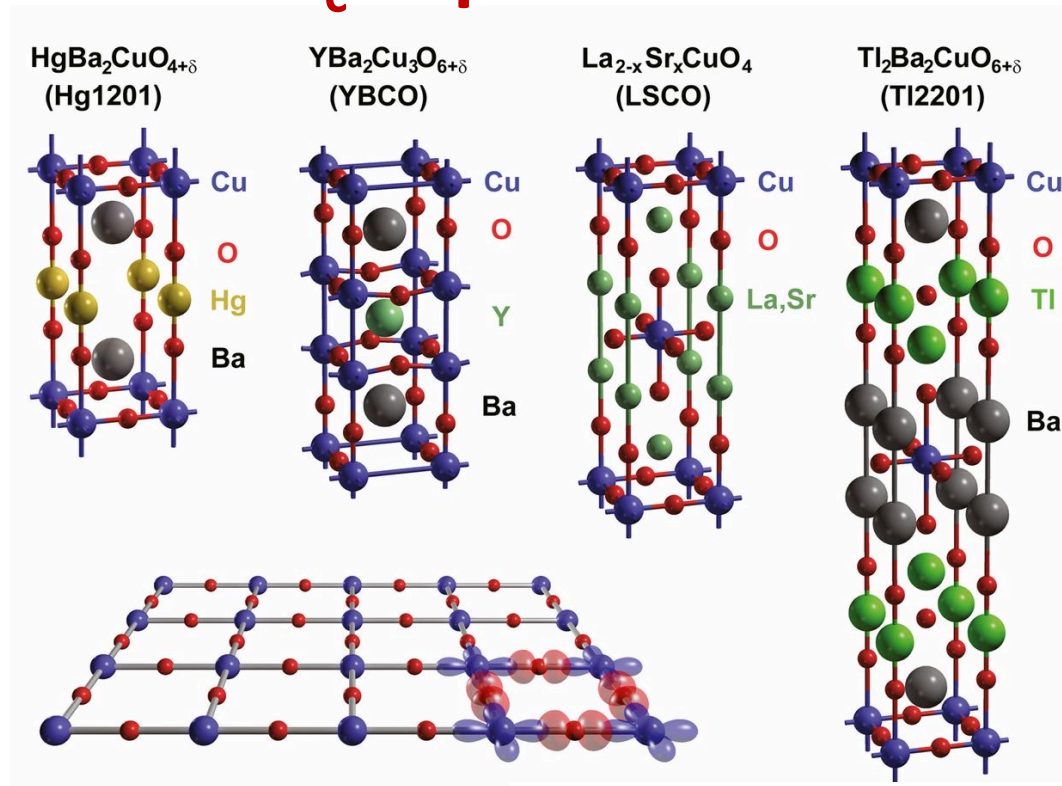


Magnetic excitations (magnons)

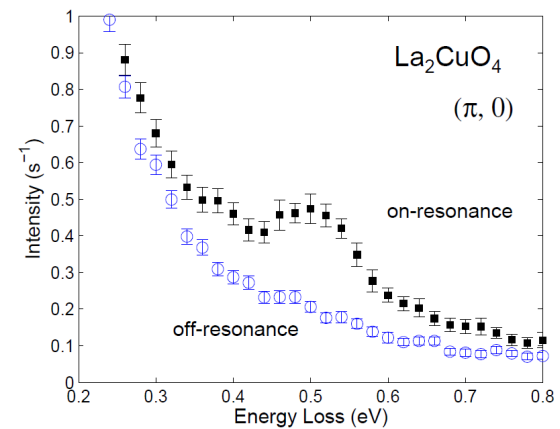
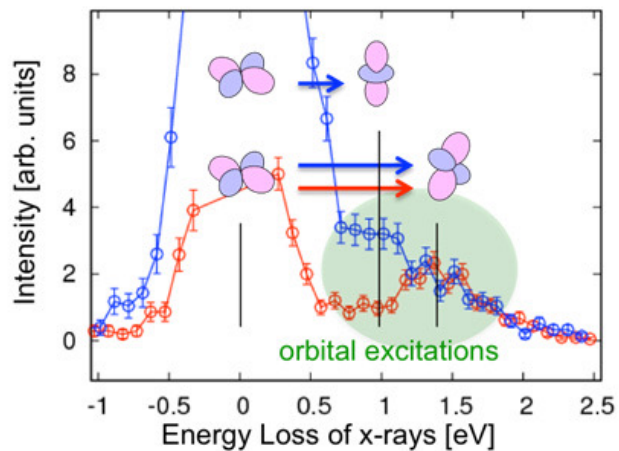


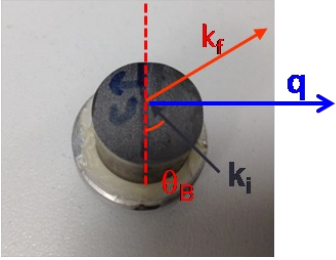
collective excitation of the electron's spin structure in a crystal structure

# Yüksek $T_c$ Süperiletkenleri



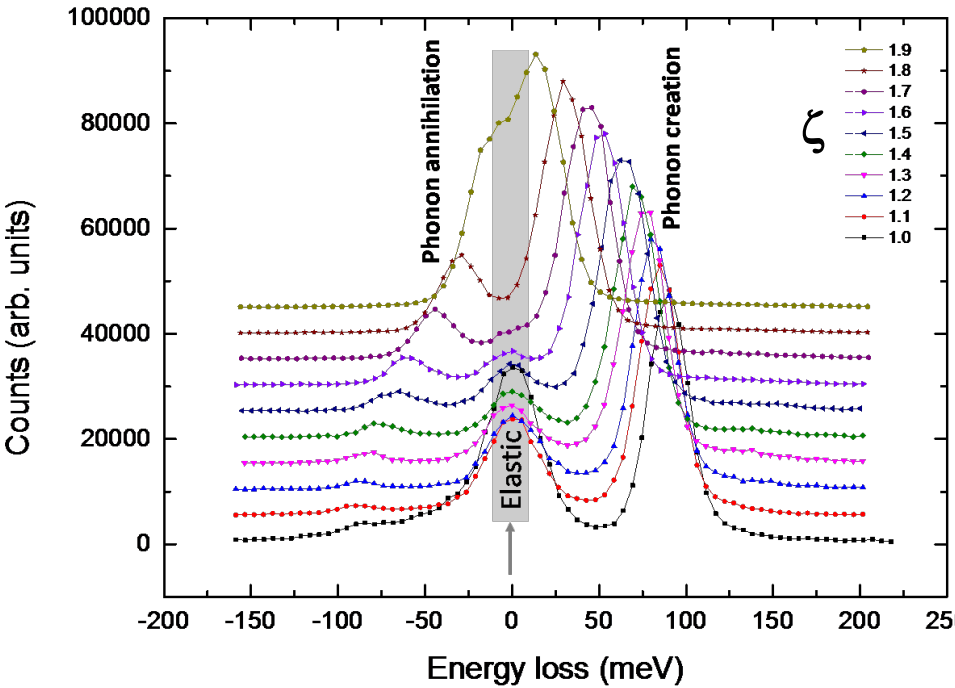
Two-magnon excitations in Cu K-RIXS



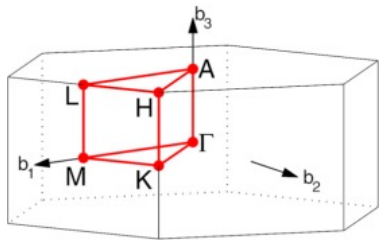
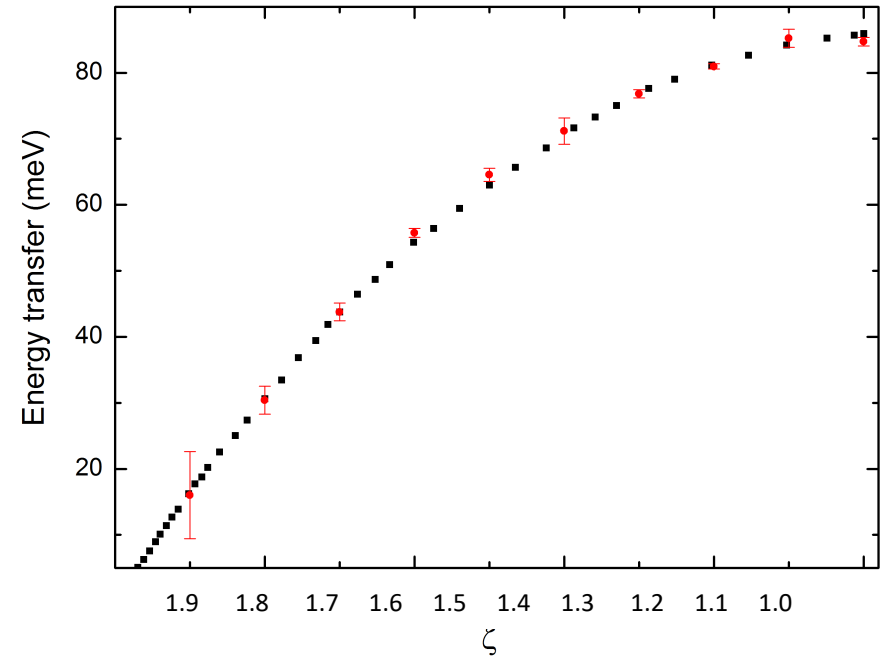


*D.Ketenoglu et al., J. Synchrotron Rad. 22 (2015) 961-967*

## Berilyum tek kristalinde [00 $\zeta$ ] yönü boyunca fonon uyarımları

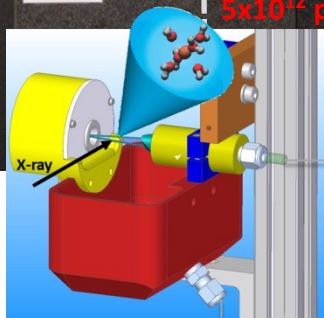
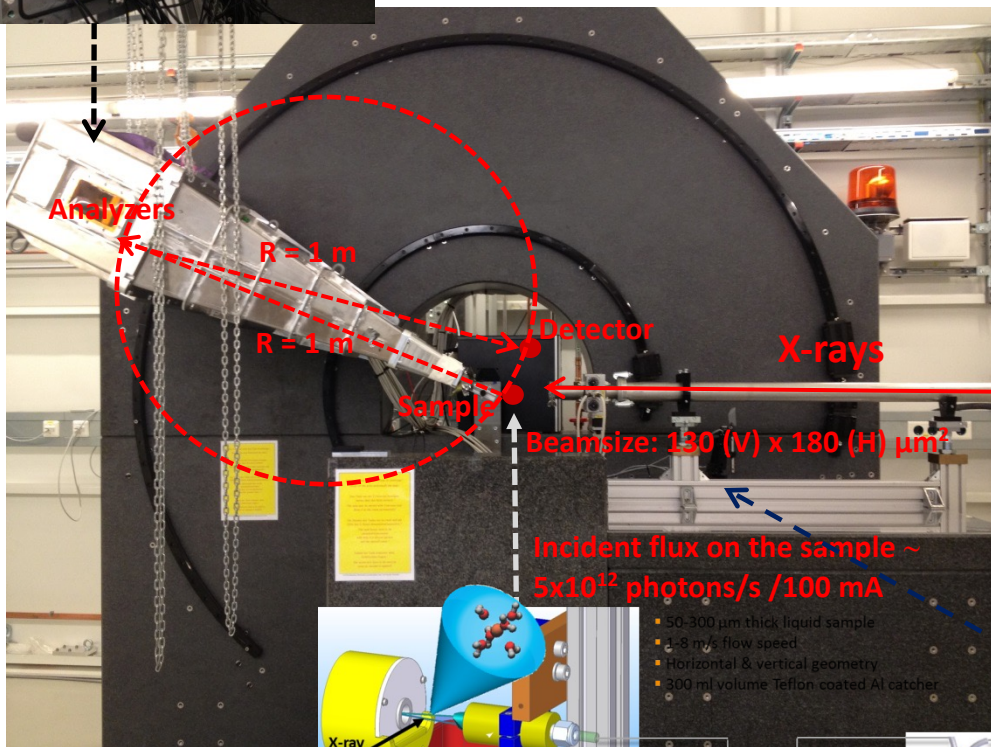
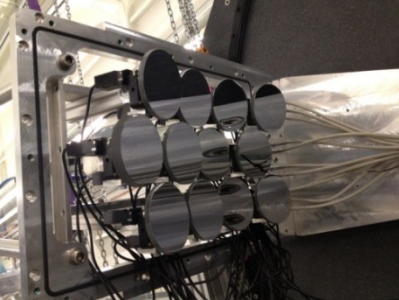


Data kaydetme süresi: 300 s



- 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**

- 50-300  $\mu\text{m}$  thick liquid sample
- 1-8 m/s flow speed
- Horizontal & vertical geometry
- 300 ml volume Teflon coated Al catcher

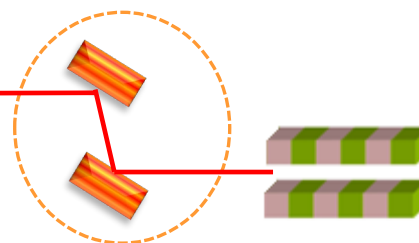


← Incident energy = 9.6 - 11.2 keV

**Si(311)**

Energy = 10 keV  
 $\Delta E \sim 250\text{ meV}$

**KB mirrors**

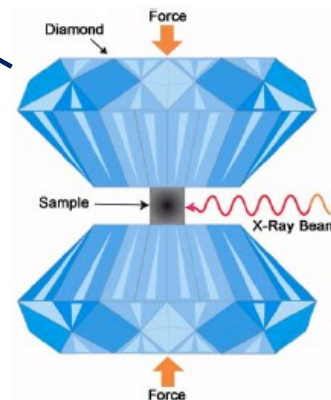


**Double Crystal Monochromator (DCM)**

**U32 undulators**

Length: (5m+5m)

Minimum gap: 12.7mm  
 Energy: 4 keV – 11 keV

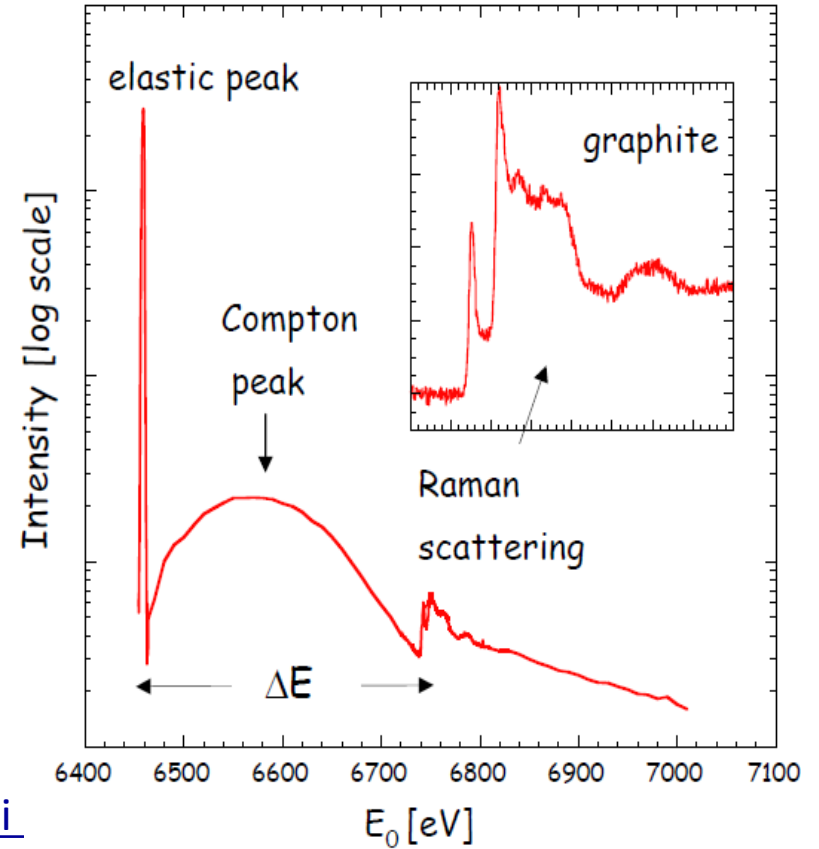
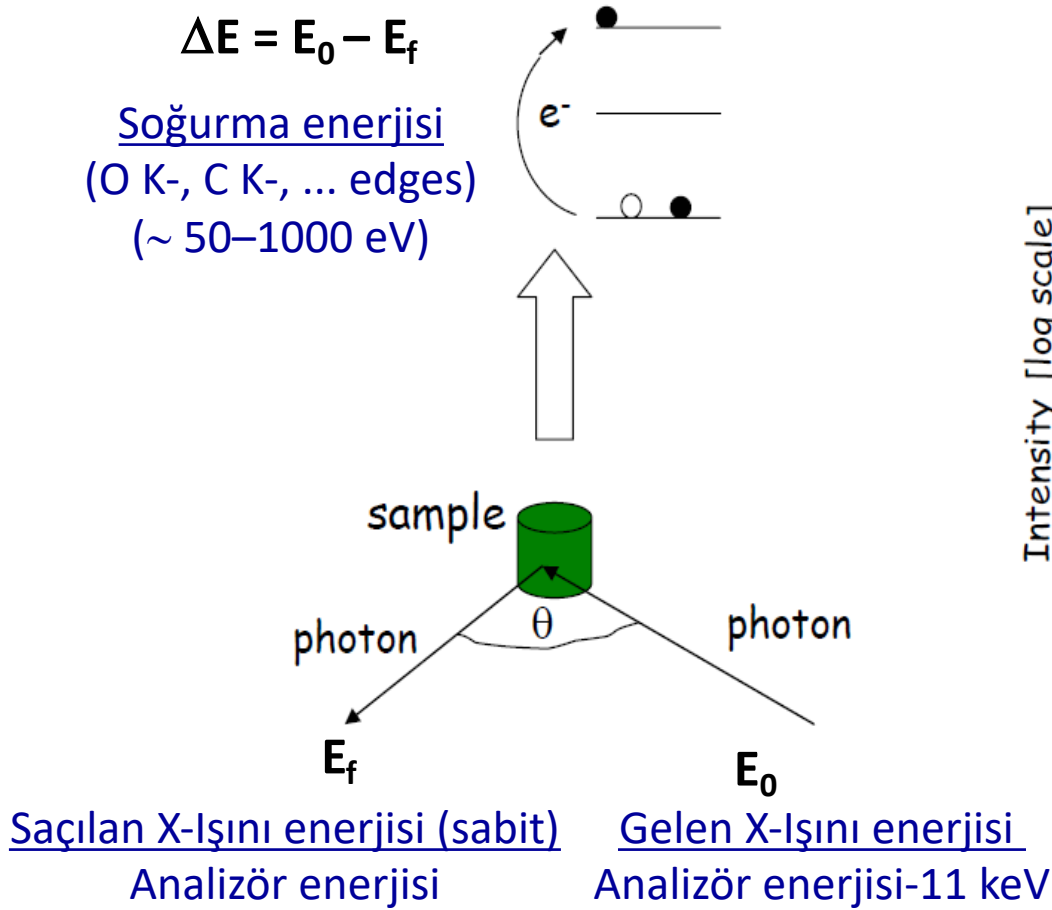


**Diamond Anvil Cell**

*Diamond-anvil cell.*

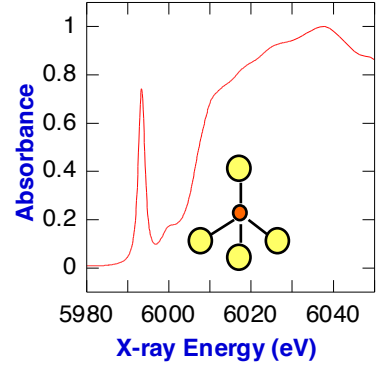
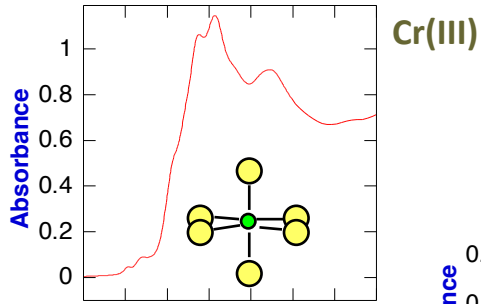
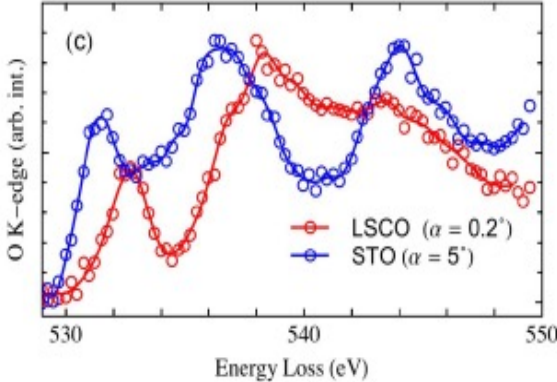
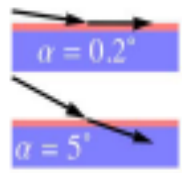






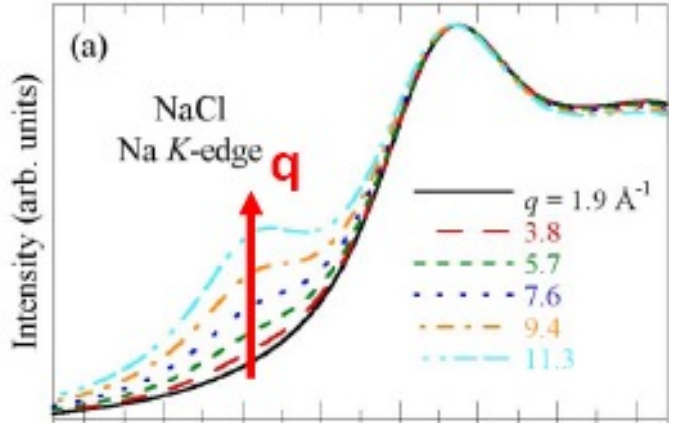
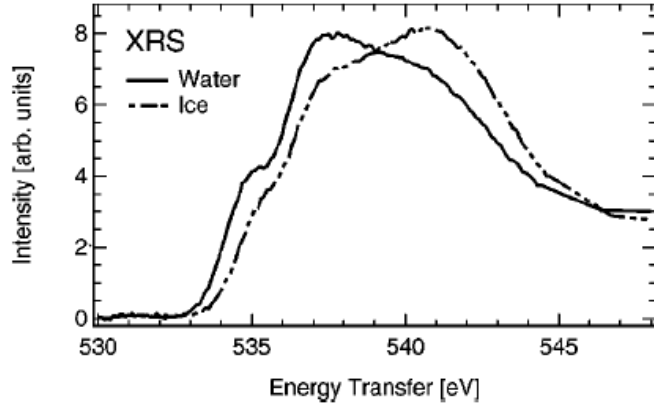
# XRS Deneeyleri

Sample: 10 nm-thick  $\text{La}_{0.6}\text{Sr}_{0.4}\text{CoO}_3$  (LSCO) on  $\text{SrTiO}_3$  (STO)



*Phys. Rev. Lett.* 106 (2011) 037401

## O K-edge

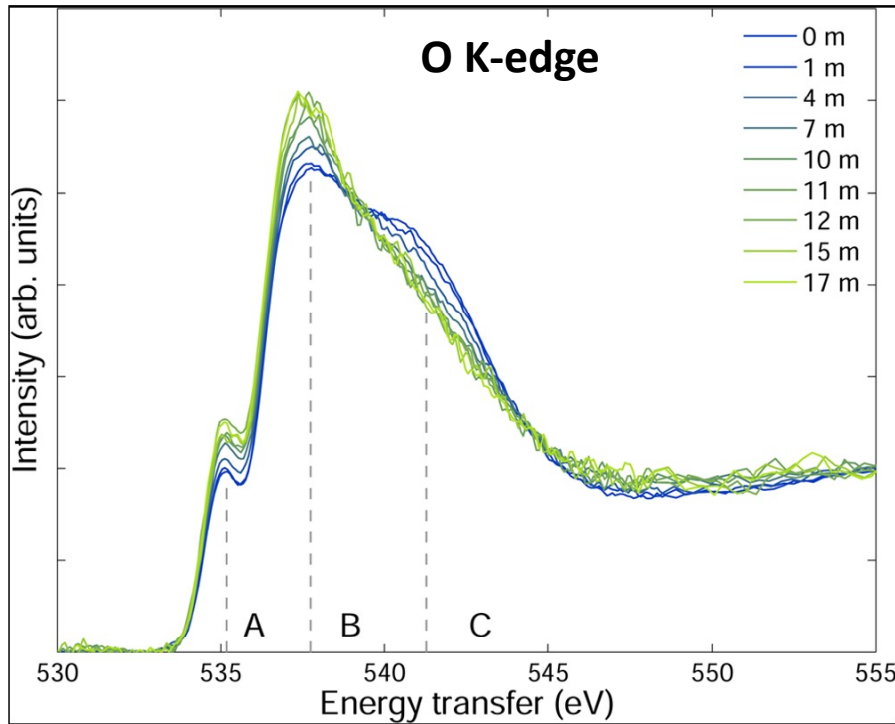


*Phys. Rev. B* 80 (2009) 045105

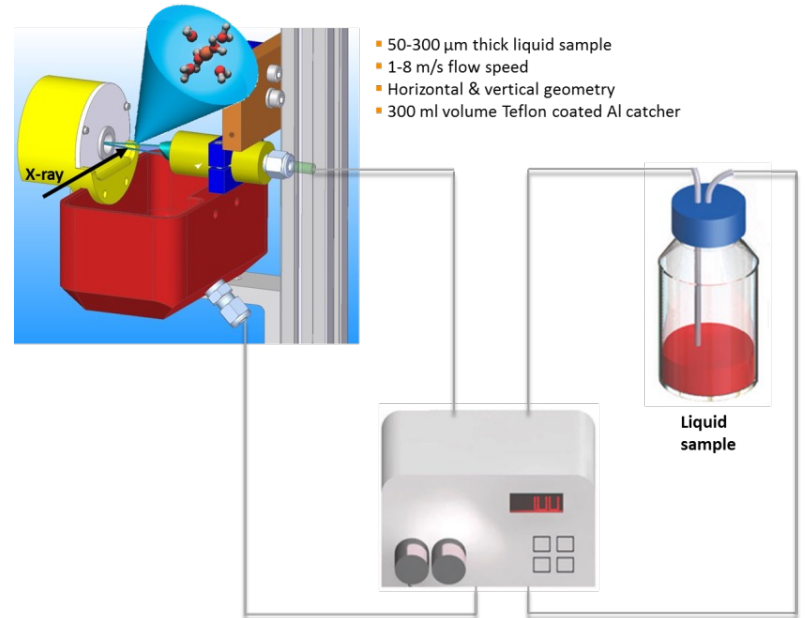
*Physical Review B* 66, 092107 (2002) 1-4

## • Sıvı örneklerin ölçümü

Hydrogen-bond network of water in aqueous LiCl solutions

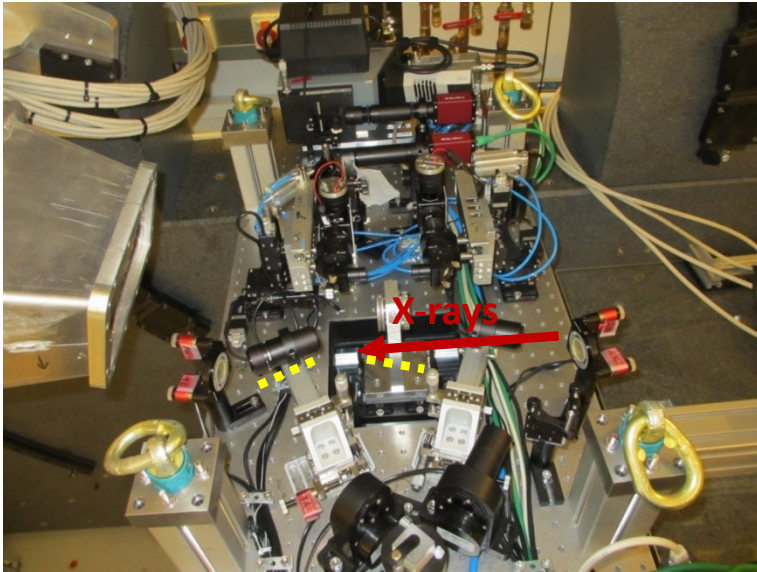
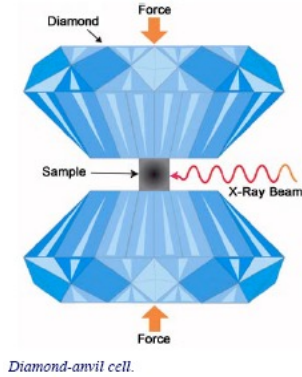


## Liquid jet



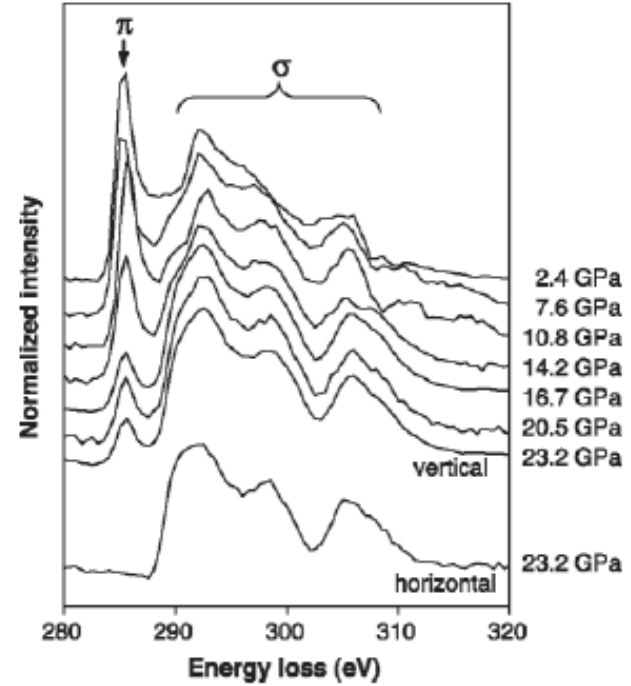
*J. Phys. Chem. B 117 (2013) 16506–16511*

• Yüksek basınçtaki örneklerin ölçümü



Laser-heating ( $T \sim 3000\text{K}$ ) for high-temperature & high-pressure studies

C K-edge

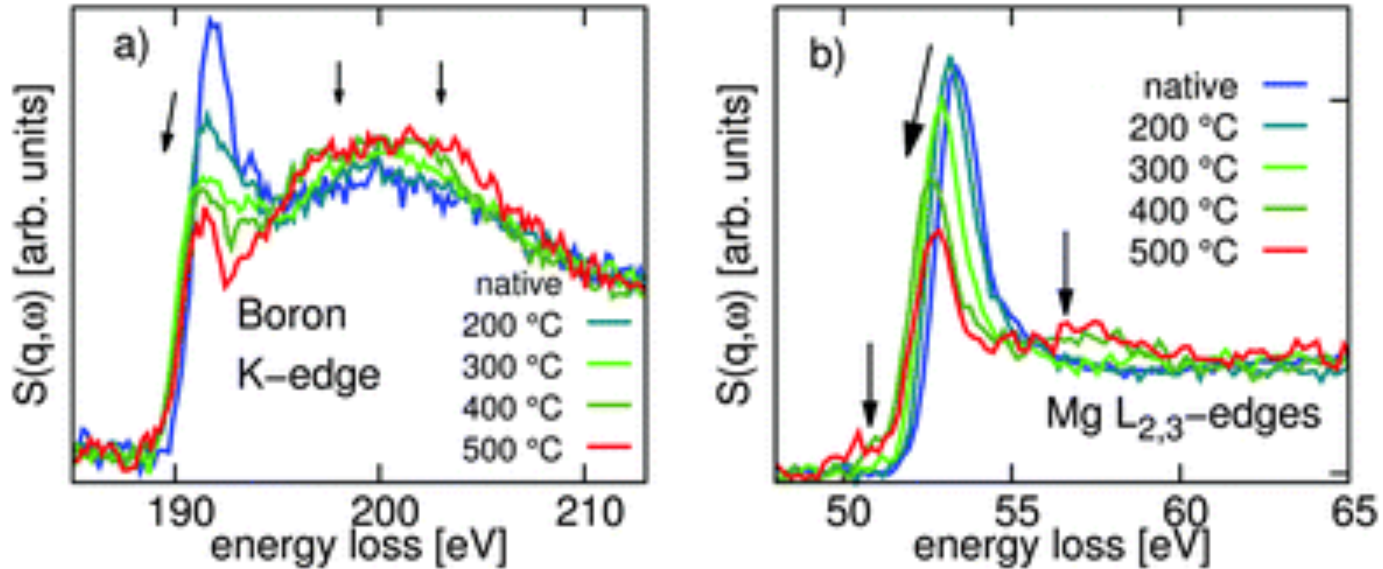


*Science 302 (2003) 425*

Pressure changes bonding in graphite  
XRS reveals the evolution of bonding and transformation of graphite to a new superhard phase  
Approximately half of the  $sp^2$  converted to  $sp^3$

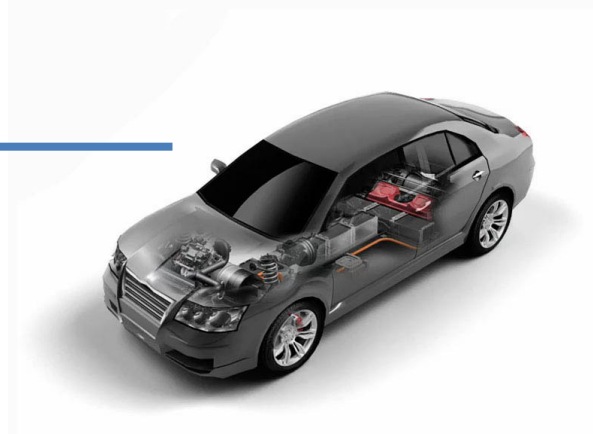
- Yüksek sıcaklıktaki örneklerin ölçümü

In-situ study of the thermal decomposition of  $\text{Mg}(\text{BH}_4)_2$  in a hydrogen atmosphere of up to 4 bar and up to 500 °C

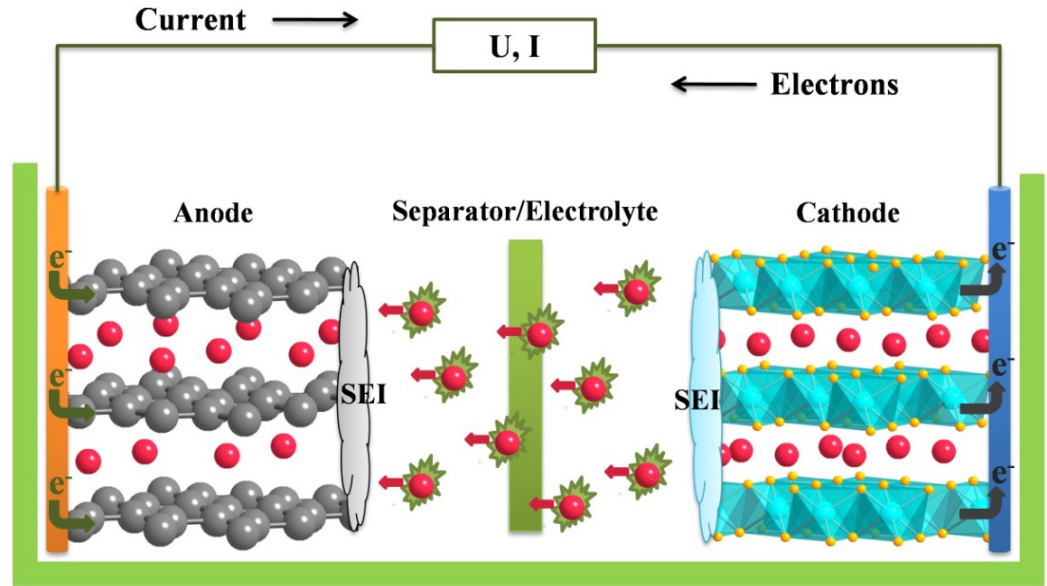
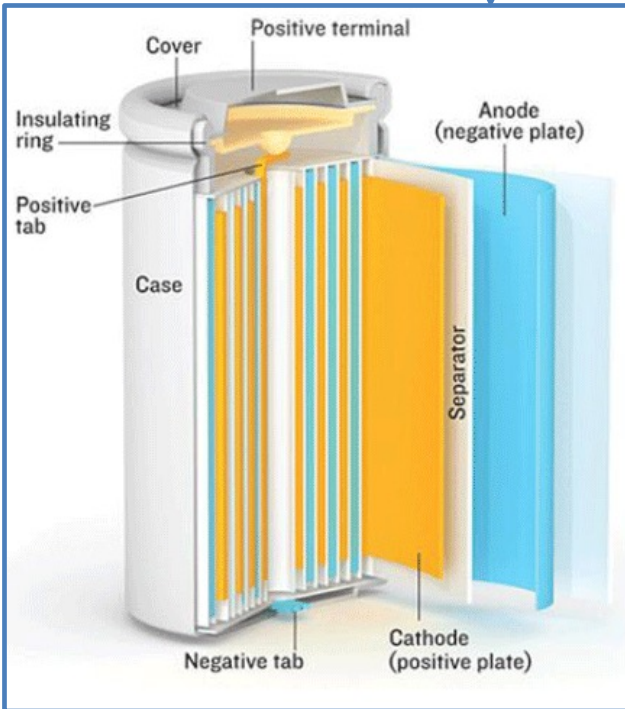


*Phys. Chem. Chem. Phys.* 18 (2016) 5397-5403

• Lityum iyon pilleri

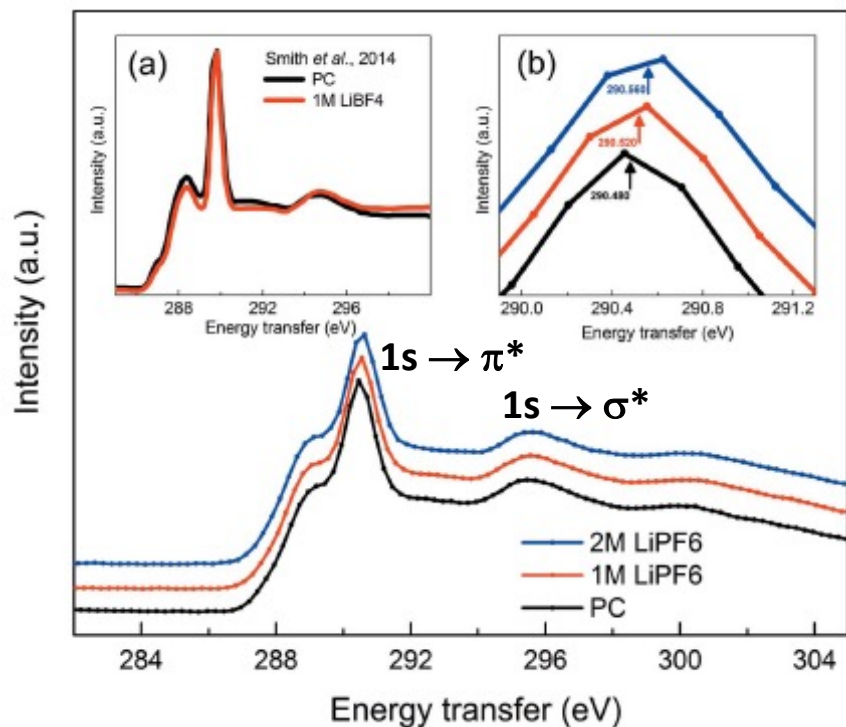


LIB cell structure



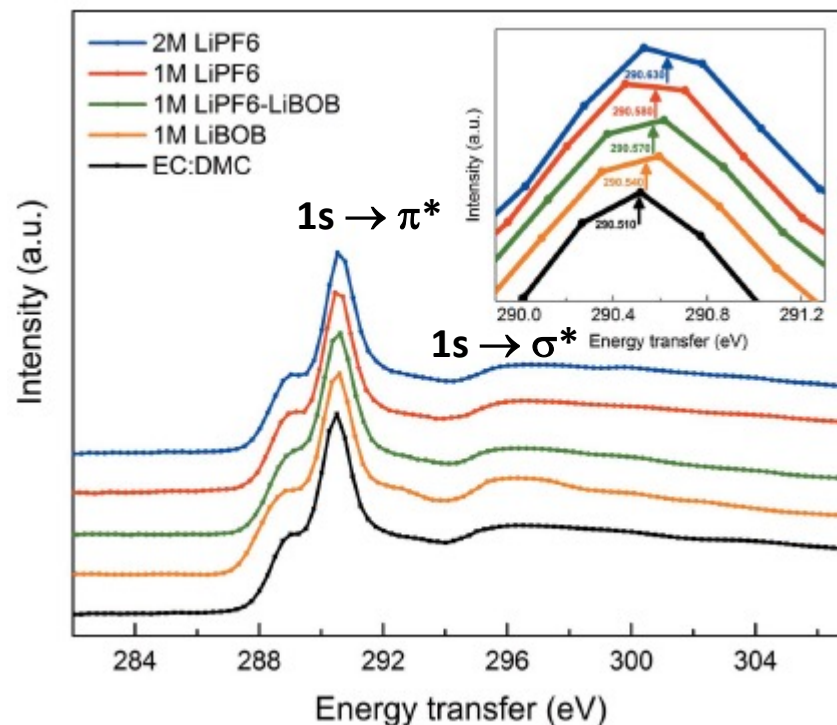
# Carbon K-edge XRS spectra

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



## Shifts relative to pure PC

- 1M LiPF<sub>6</sub> ➡ 0.04 eV
- 2M LiPF<sub>6</sub> ➡ 0.08 eV



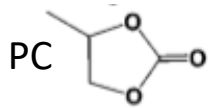
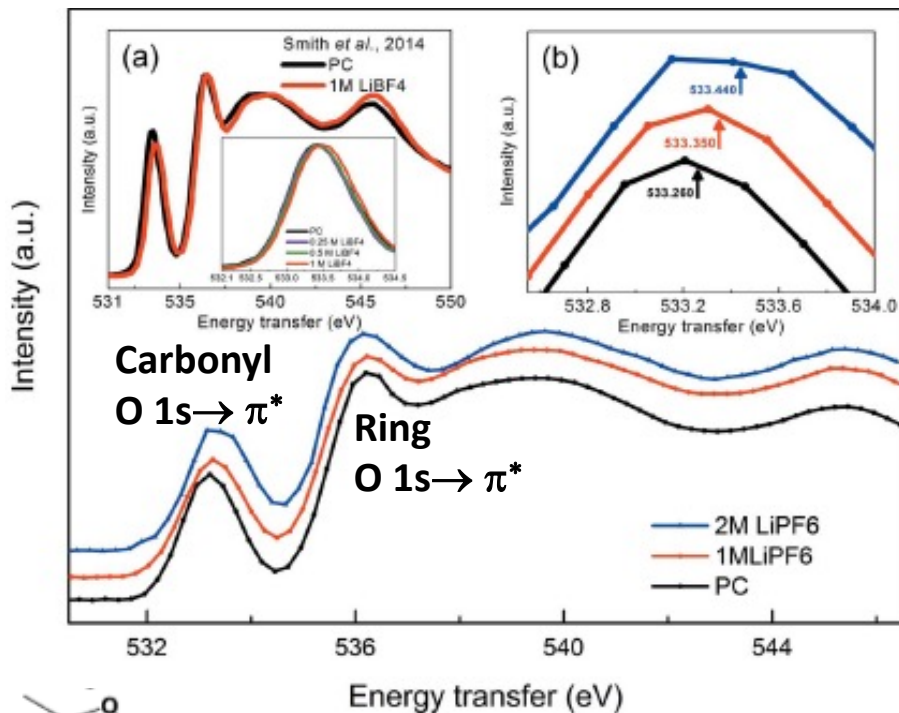
## Shifts relative to EC:DMC (1:1 vol.)

- 1 M LiBOB ➡ 0.03 eV
- 5 wt % LiBOB + LiPF<sub>6</sub> ➡ 0.06 eV
- 1M LiPF<sub>6</sub> ➡ 0.07 eV
- 2M LiPF<sub>6</sub> ➡ 0.12 eV

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

# Oxygen K-edge XRS spectra

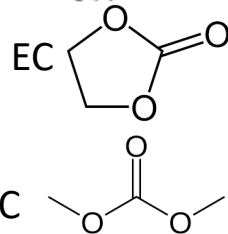
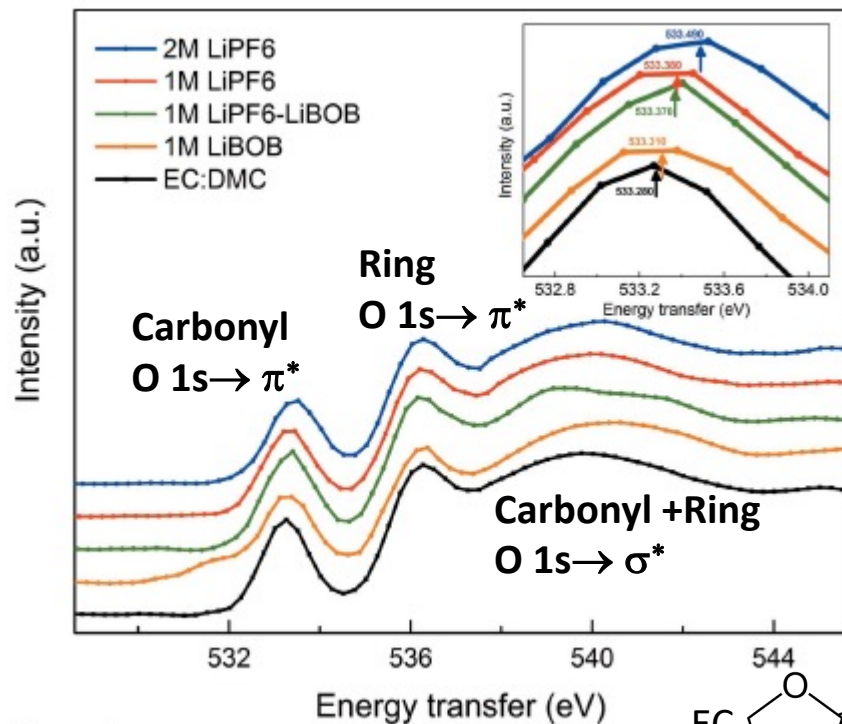
*D.Ketenoglu et al., J. Synchrotron Rad. 25 (2018) 537–542*



Ring oxygens are unaffected by the addition of the salt

**Carbonyl  $\pi^*$  peak shifts relative to pure PC**

- 1M LiPF<sub>6</sub> → 0.06 eV
- 2M LiPF<sub>6</sub> → 0.18 eV



**Carbonyl  $\pi^*$  peak shifts relative to EC:DMC (1:1 vol.)**

- 1 M LiBOB → 0.03 eV
- 5 wt % LiBOB + LiPF<sub>6</sub> → 0.09 eV
- 1M LiPF<sub>6</sub> → 0.1 eV
- 2M LiPF<sub>6</sub> → 0.21 eV



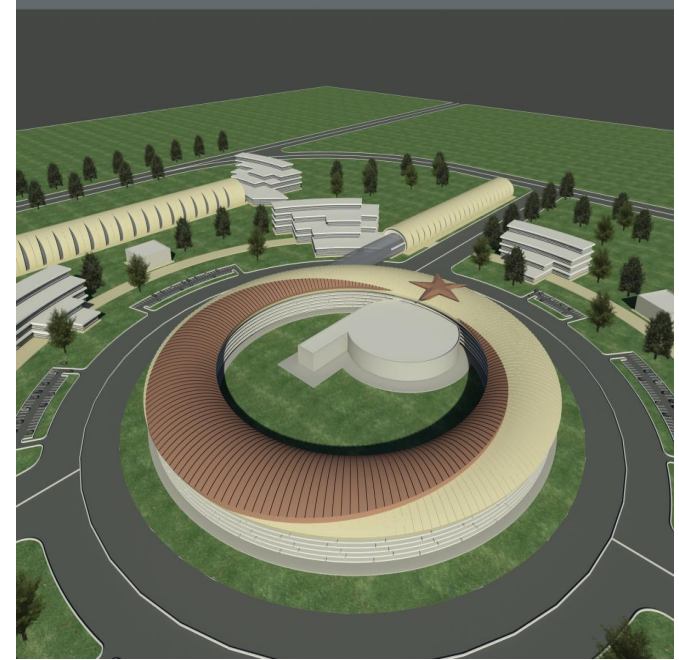
# Türk Hızlandırıcı Merkezi (Plan)



# THM Sinkrotron Işınımı Tesisi (TURKAY)

## Ana Karakteristikleri:

- Demet Enerjisi: 3 GeV
- Demet Akımı: 500 mA
- Beam emittance: 0.5 nmrad
- Çevre: 477 m
- Düz Bölümler: 20x5
- ID's: Undulator and Wiggler magnets
- Demet Hatları: ~ 30



<http://thm.ankara.edu.tr/bilgi-notu-turkay/>

# ■ TURKAY kullanıcı potansiyeli

75

## • Türkiye:

- 81 ilde 174 Üniversite

- Ulusal Enstitüler:

Biyoteknoloji, Nanoteknoloji, Hızlandırıcı  
Maden, Tıp, Eczacılık, Seramik,  
Meteoroloji, Uzay vb konular üzerine çalışan.

- Ulusal Resmi Makamlar: TUBİTAK , TAEK, MAM

- Endüstri, Teknoparklar...



# ■ Türkiye'deki Kullanıcı Potansiyeli



## Third TAC Light Sources International Users' Meeting (TAC-LSUM2013) October 5-7, 2013, Ankara University, Ankara



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- *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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- *U. Bergmann et al., "Bulk-sensitive XAS characterization of light elements: from X-ray Raman scattering to X-ray Raman spectroscopy", Microchemical Journal 71 (2002) 221-230.*
- *Ketenoglu, D., Spiekermann, G., Harder, M., Oz, E., Koz, C., Yagci, M. C., Yilmaz, E., Yin, Z., Sahle C.J., Detlefs, B. & Yavaş, H. (2018). X-ray Raman spectroscopy of lithium-ion battery electrolyte solutions in a flow cell. Journal of synchrotron radiation, 25(2), 537-542.*
- *Synchrotron Radiation Light Sources, Briefing for SEAB, Patricia M. Dehmer*
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- *http://spectrum.ieee.org/*
- *Lightsources of the World. <http://www.lightsources.org/regions>*

