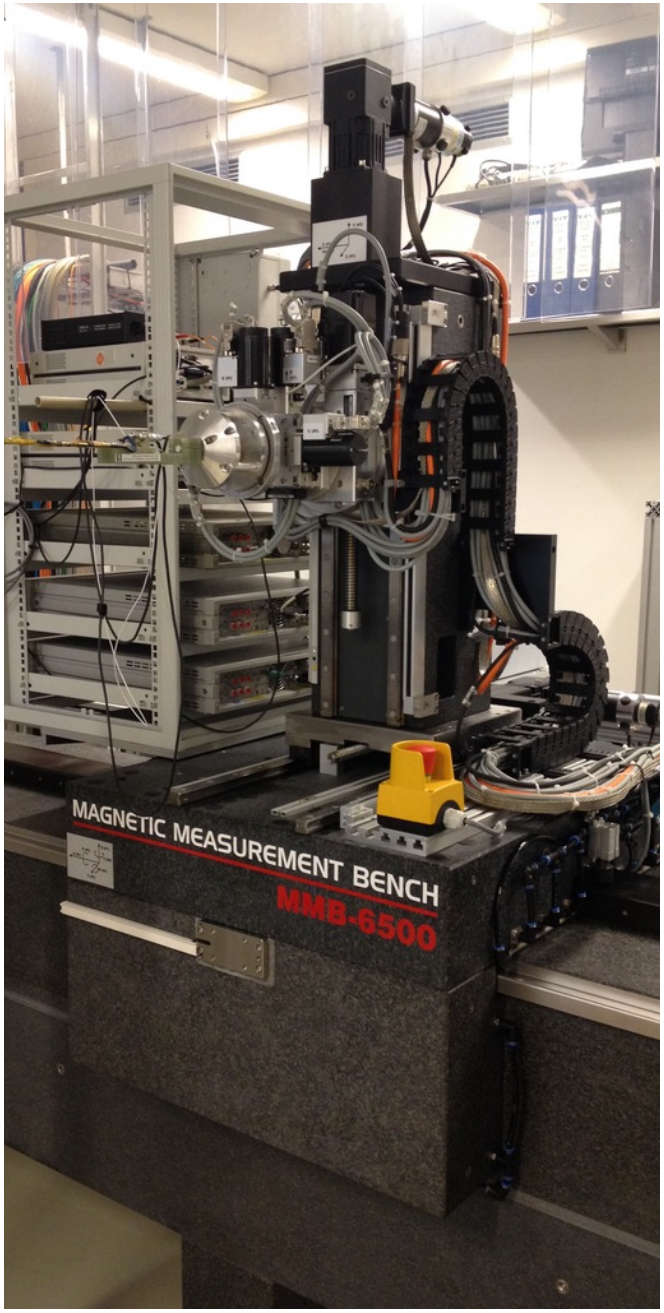

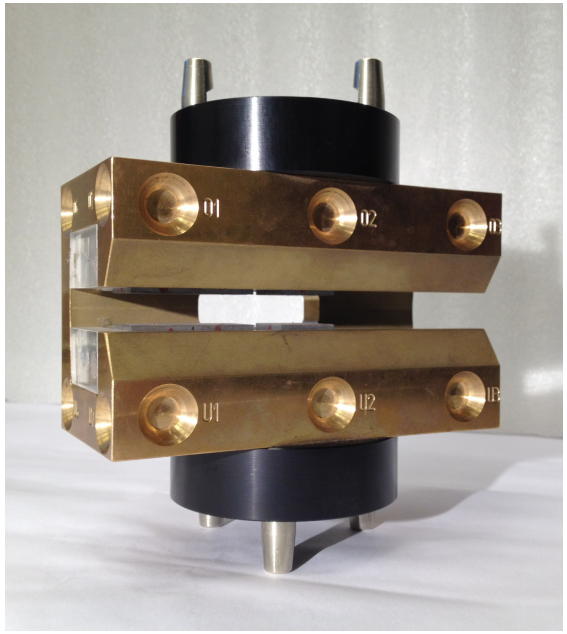

European XFEL Hibrid Undulatörleri'nin İşletime Hazır Hale Getirilmesi ve XFEL'lerin Yüksek Teknoloji Uygulamaları

Doç. Dr. Bora KETENOĞLU
Ankara Üniversitesi Mühendislik Fakültesi
Fizik Mühendisliği Bölümü
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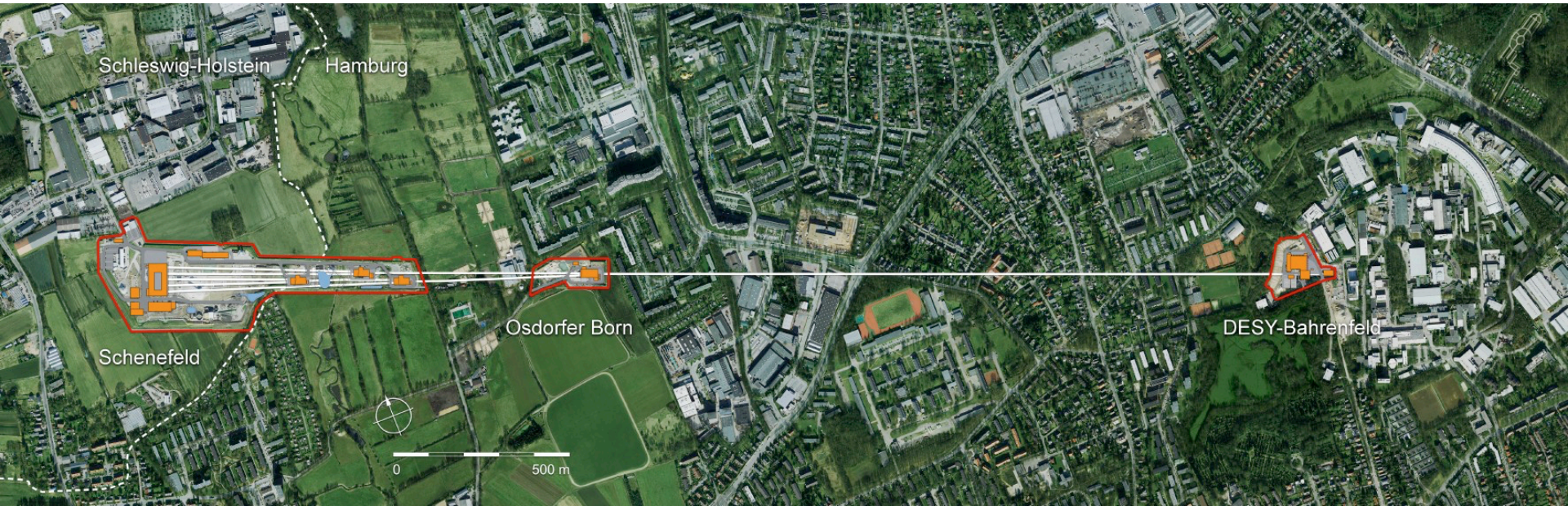
European XFEL Bilimsel Araştırma Merkezi
Hamburg, Almanya

https://www.xfel.eu



İki uçtaki tünel derinlikleri: 6 - 38 metre

Hızlandırıcı: 1.7 km uzunluğunda elektron linak

Elektron demet enerjisi 17.5 GeV

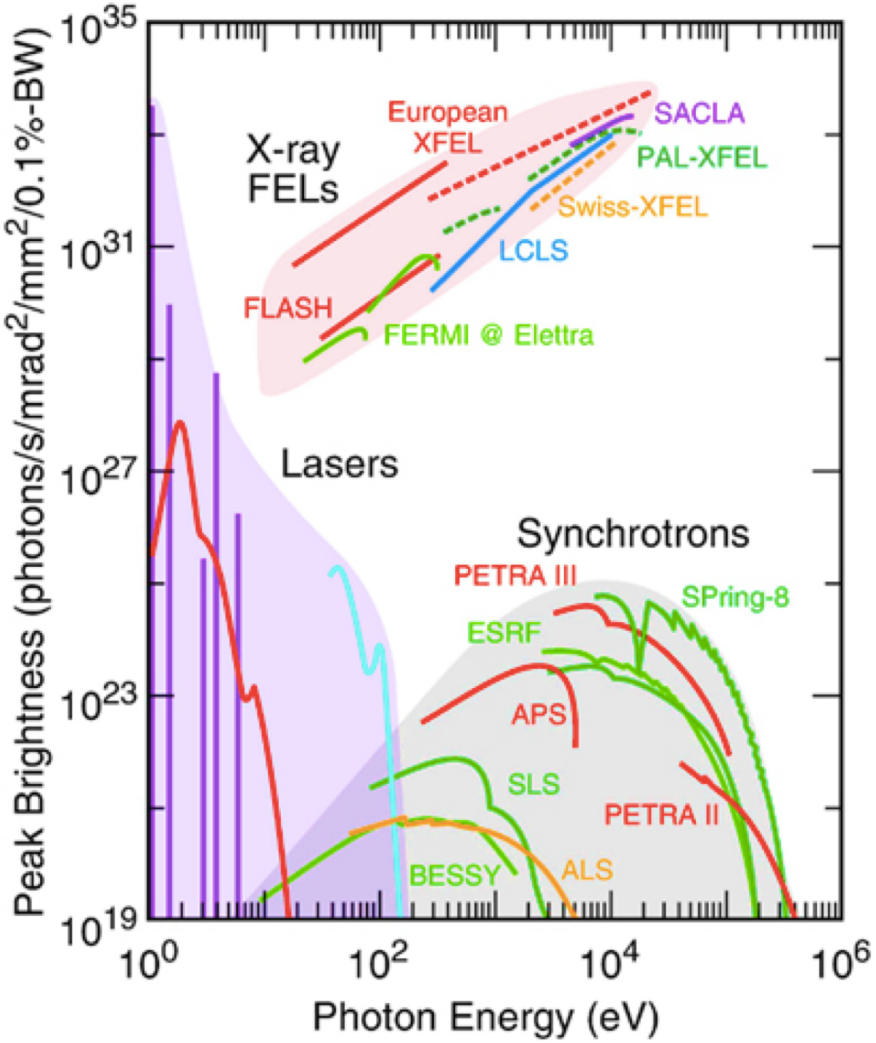
(20 GeV'e kadar artırılabiliyor)

ID'ler: Toplam 91 adet U40 ve U68 undulatörler

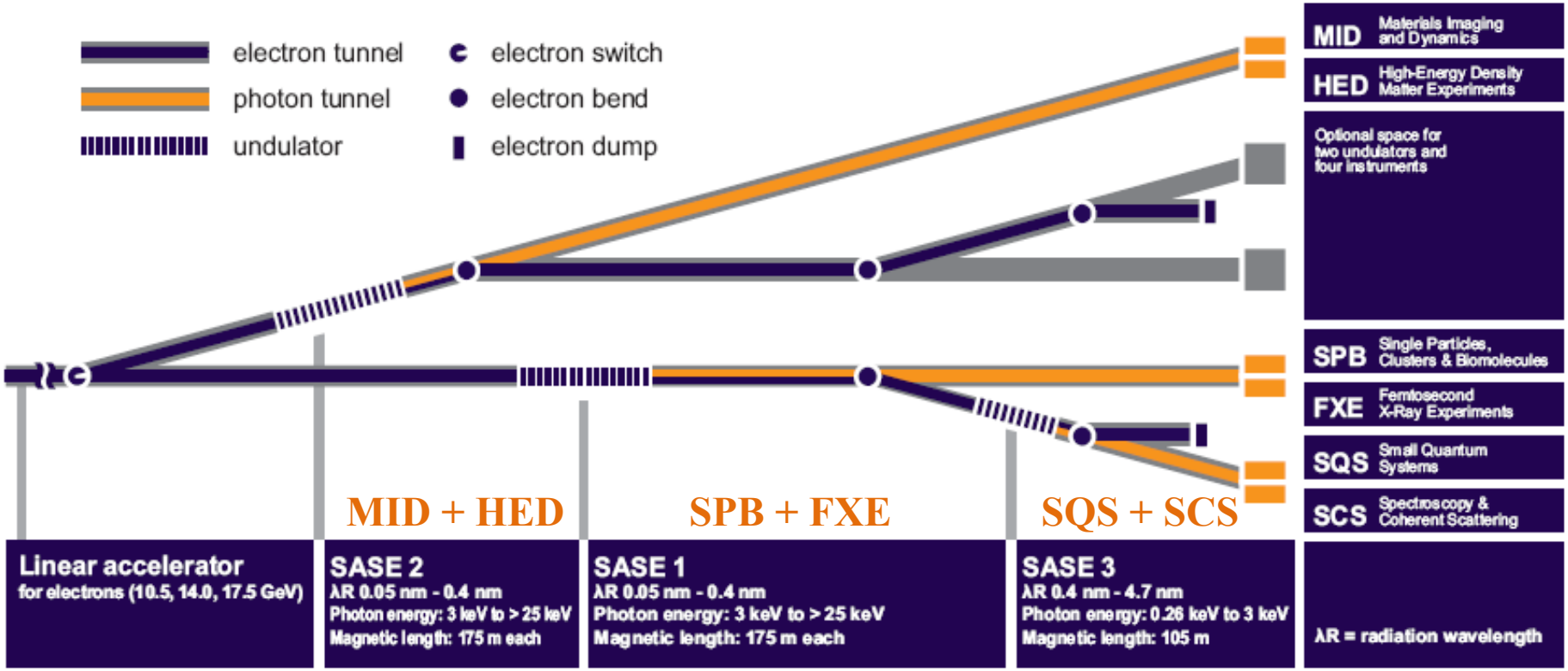
"5m uzunluğunda ve 8 ton ağırlığında"

European XFEL'in Dünya'daki diğer X-Işını Serbest Elektron Lazeri Tesisleri ile Karşılaştırması

Facility	se duration VHM) (fs)
FLASH	-200
LCLS	400
SACLA	10
FERMI	-100
PAL-XFEL	100
SwissFEL	20
European XFEL	150
SXFEL	-1,000
LCLS-II (HE	500
SHINE	500

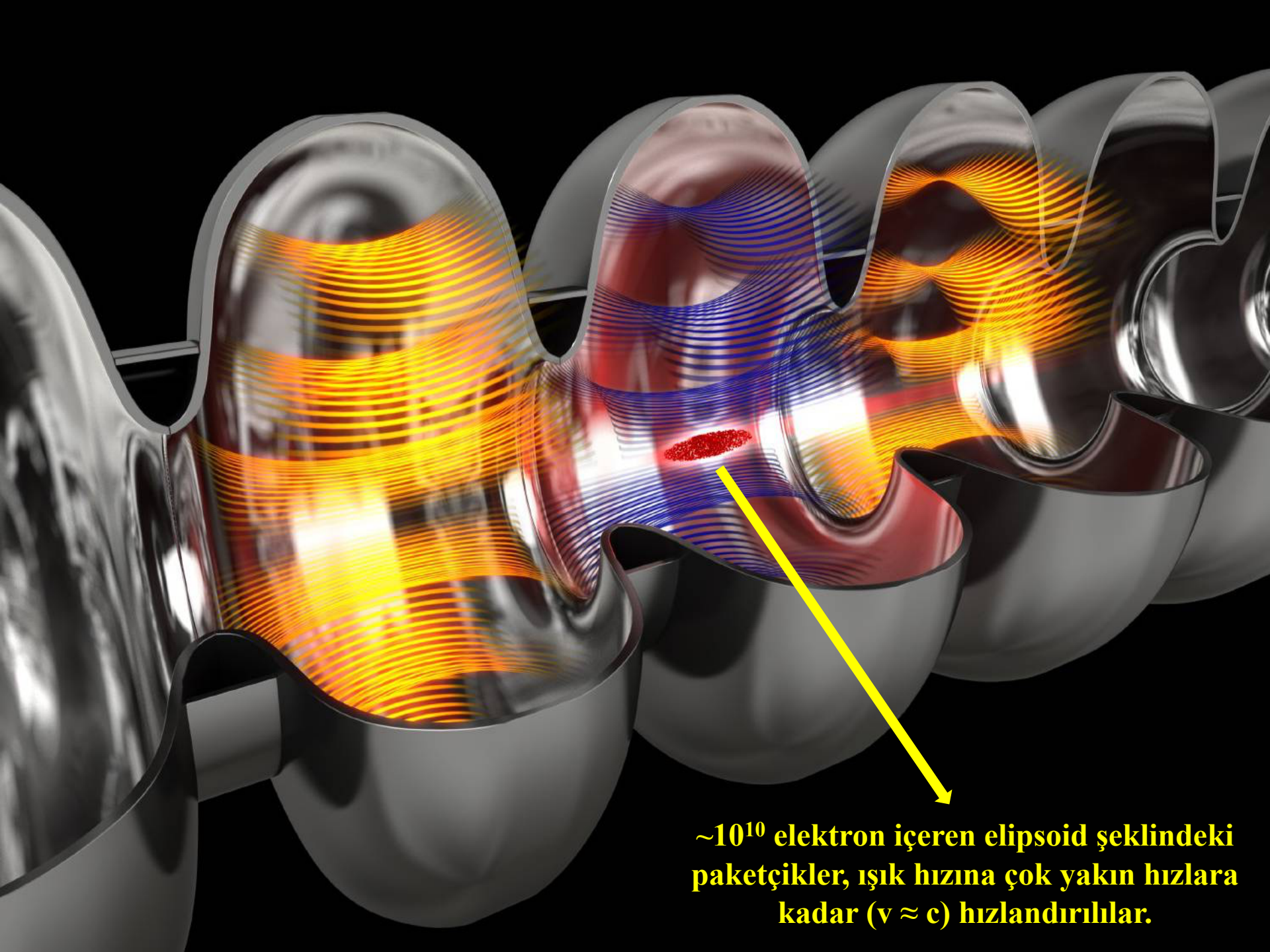


Almanya/Hamburg'da Çalışmakta Olan 3.4 km Uzunluklu X-Işını Dalgaboylu Serbest Elektron Lazeri Tesisi

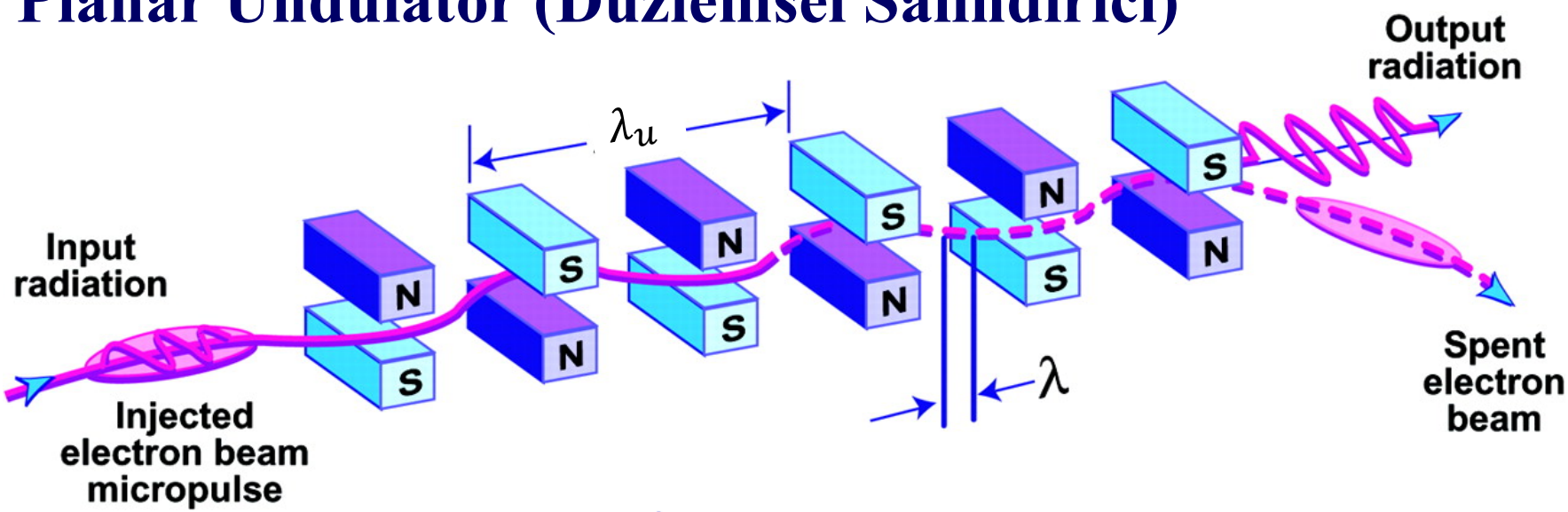


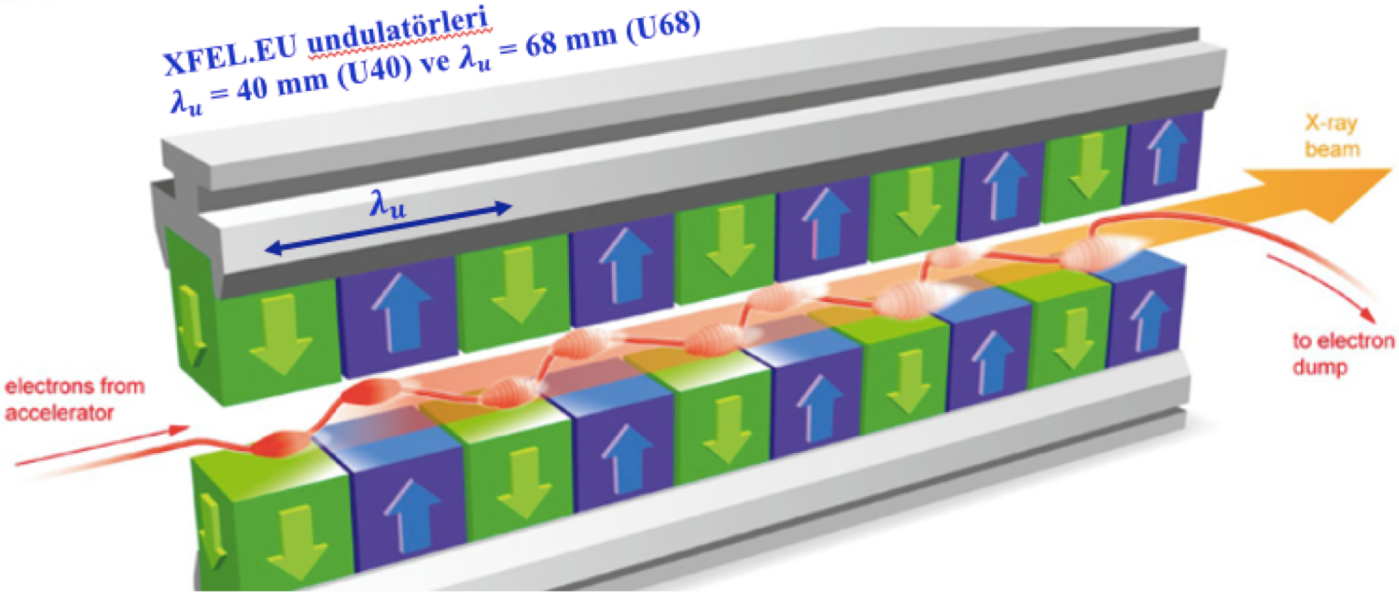
Planlanan Bilimsel Deneyler	nm Ölçekli Yapılar	Ultrahızlı Süreçler	Sıradışı Durumlar	Demet Hattı
SPB (Tek Parçacıklar, Yığınlar & Biyomoleküller) Ultrahızlı koherent kırınım görüntüleme, Tek parçacıkların yapı belirlenmesi: atomik yığınlar, biyomoleküller, virüs parçacıkları ve hücreler	■	■		SASE1
FXE (Femtosaniye X-ışını Deneyleri) Katıların, sıvıların ve gazların dinamiklerinin zaman çözünürlüklü incelemeleri		■		SASE1
MID (Malzeme Görüntüleme ve Dinamikleri) Nanoaygıtlarınyapı belirlenmesi ve nano boyutta dinamikler	■	■		SASE2
HED (Yüksek Enerji Yoğunluklu Madde Deneyleri) Sert X-ışını dalgaboylu SEL ile maddenin sıradışı durumlarda incelenmesi , ömeğin: yoğun plazmanın algılanması		■	■	SASE2
SQS (Küçük Kuantum Sistemleri) Şiddetli alanlarda atomların, iyonların, moleküllerin ve yığınların incelenmesi, Doğrusal olmayan fenomen	■	■	■	SASE3
SCS (Spektroskopi ve Koherent Saçılma) Elektronik ve atomik yapı ve yumuşak X-ışınları ile nanosistemlerin dinamiği ve tekrarlanamayan biyolojik nesneler	■	■		SASE3


Doğrusal Elektron Hızlandırıcısı
IN COLLABORATION WITH
European XFEL
DESY
ABB


~10^{10} elektron içeren elipsoid şeklindeki paketçikler, ışık hızına çok yakın hızlara kadar ($v \approx c$) hızlandırılılar.

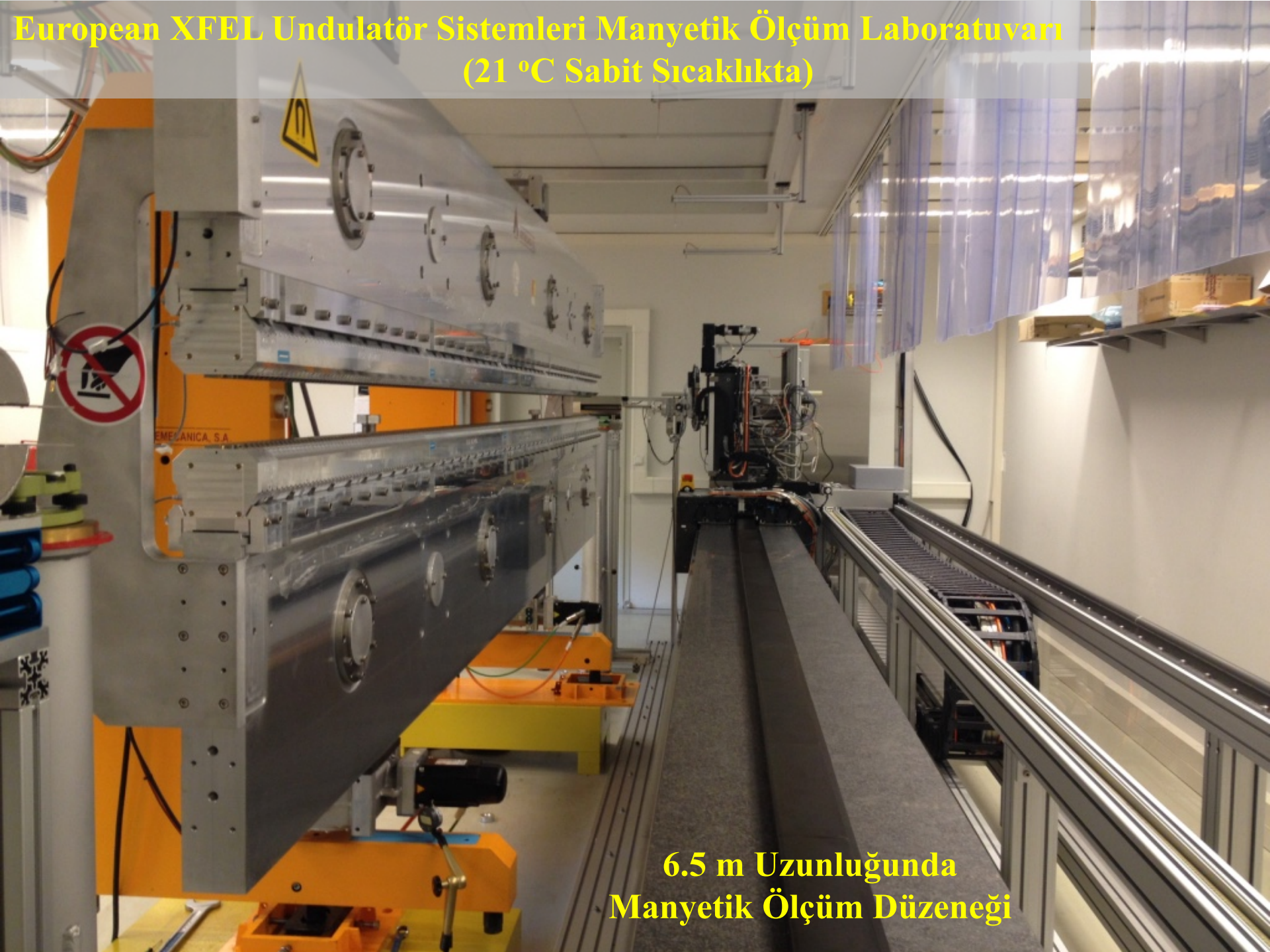
Planar Undulator (Düzlemsel Salındırıcı)



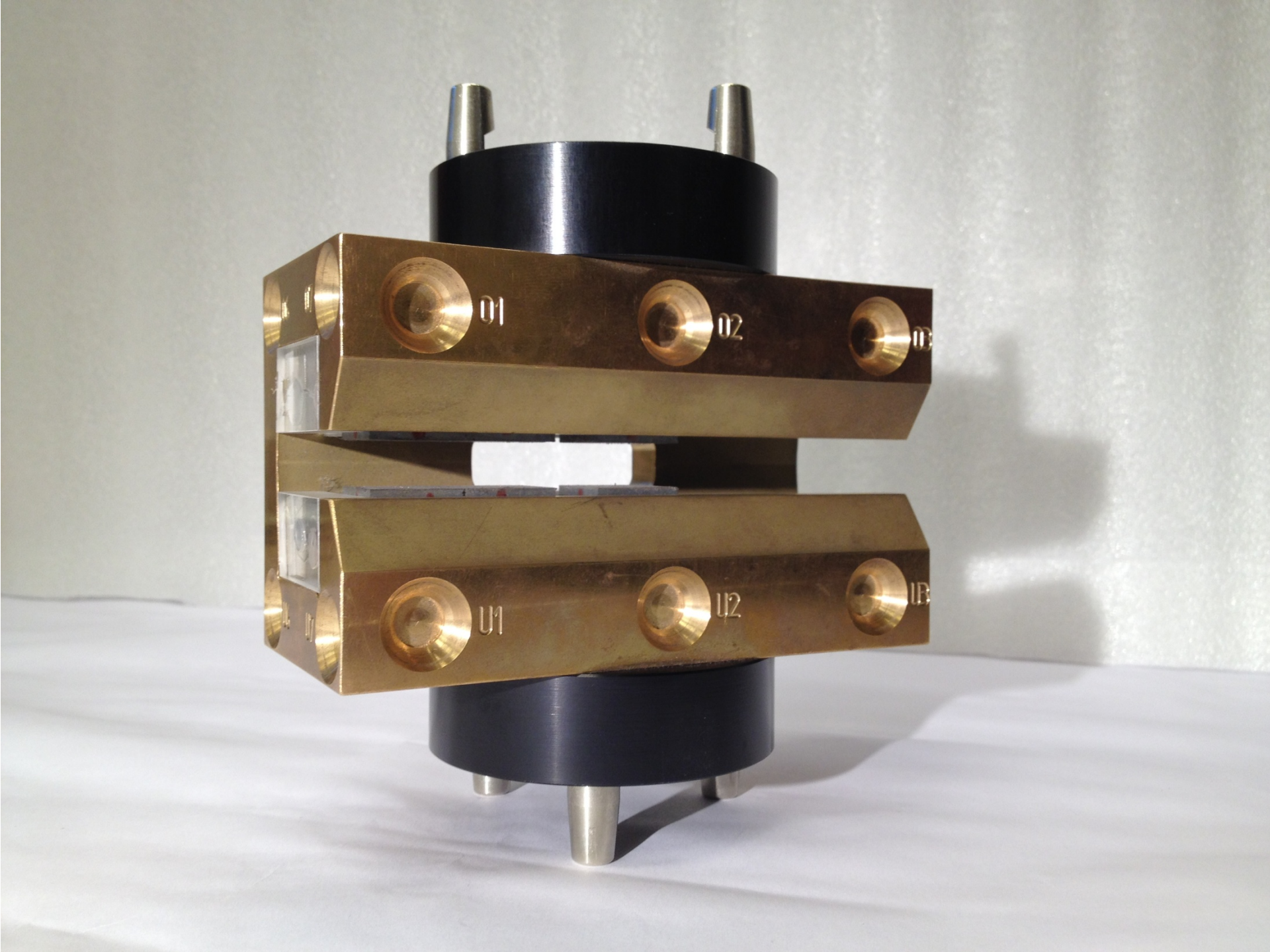


5m Uzunluğunda U40 Undulatörü
(Birbirinden Bağımsız 4 Ayrı Motor ile Kontrol)

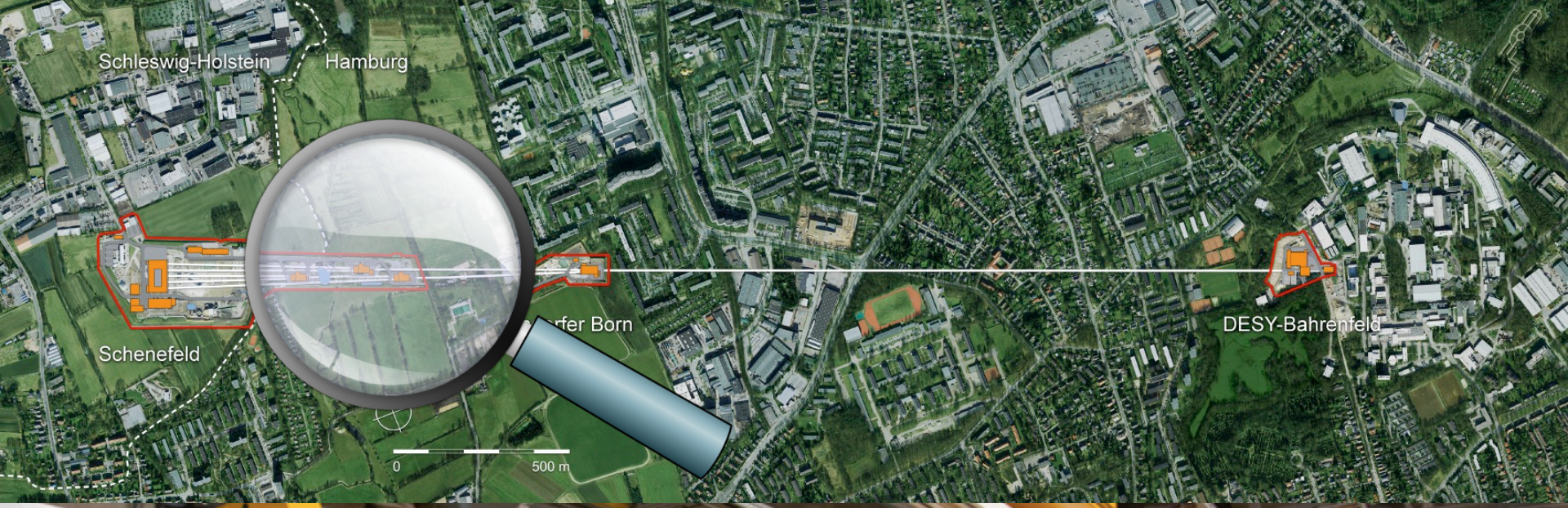
European XFEL Undulatör Sistemleri Manyetik Ölçüm Laboratuvarı
(21 ºC Sabit Sıcaklıkta)



6.5 m Uzunluğunda
Manyetik Ölçüm Düzeneği


O1
O2
U1
U2

Undulatörlerin bütün kutupları manyetik labda başarılı bir şekilde ayarlanıp landmark ölçümleri yapıldıktan sonra, tünele transfer edilmeye hazır hale gelirler.


Schleswig-Holstein
Hamburg
Schenefeld
rfer Born
DESY-Bahrenfeld
0
500 m

X-ışını Dalgaboylu Serbest Elektron Lazerleri'nin Disiplinlerarası Kullanım Alanları

Fizik'te
X-ışını Serbest Elektron Lazeri Deneyleri

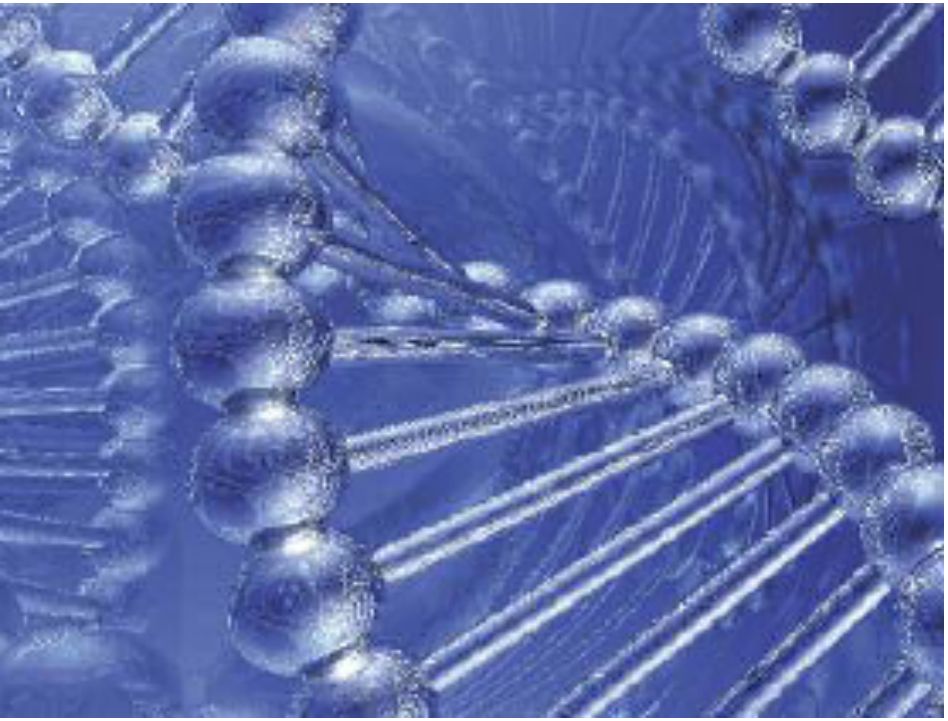
Katıların, sıvıların, gazların **statik özellikleri**

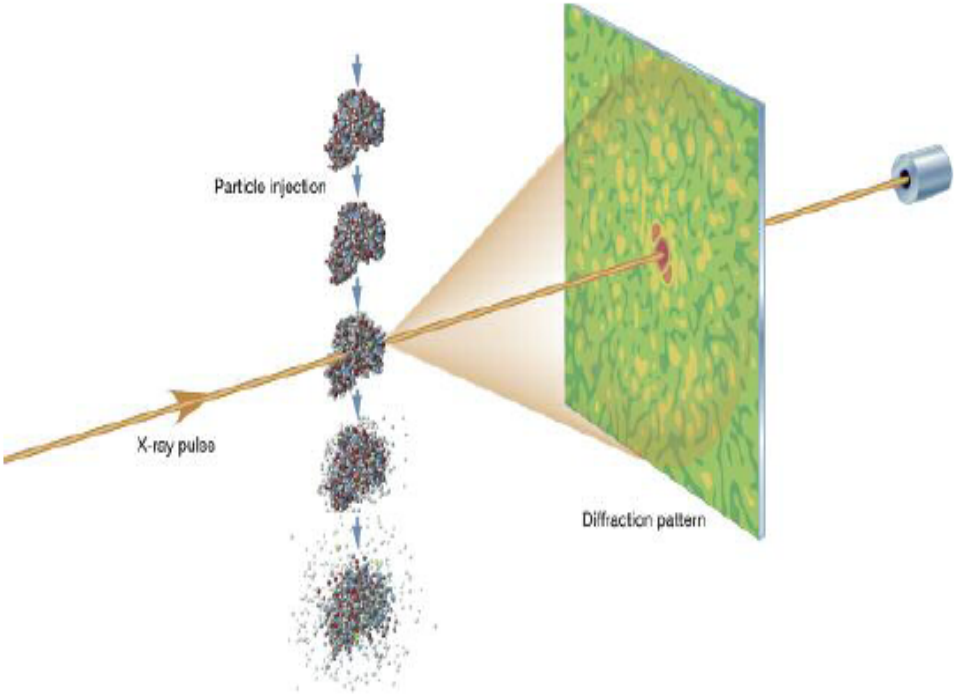
Elektrik veya magnetik alan atmaları yada ultrakısa optik lazer flaşları ile başlatılan **dinamik süreçler**

Optik ışık atmaları ile tetiklenen **faz geçişleri ve titreşimleri** süreçleri

Dayanıklılık ve elastiklik gibi geliştirilmiş özellikli yeni malzemeler için **kristallenme veya çatlak oluşumu ve yayılımı** süreçleri

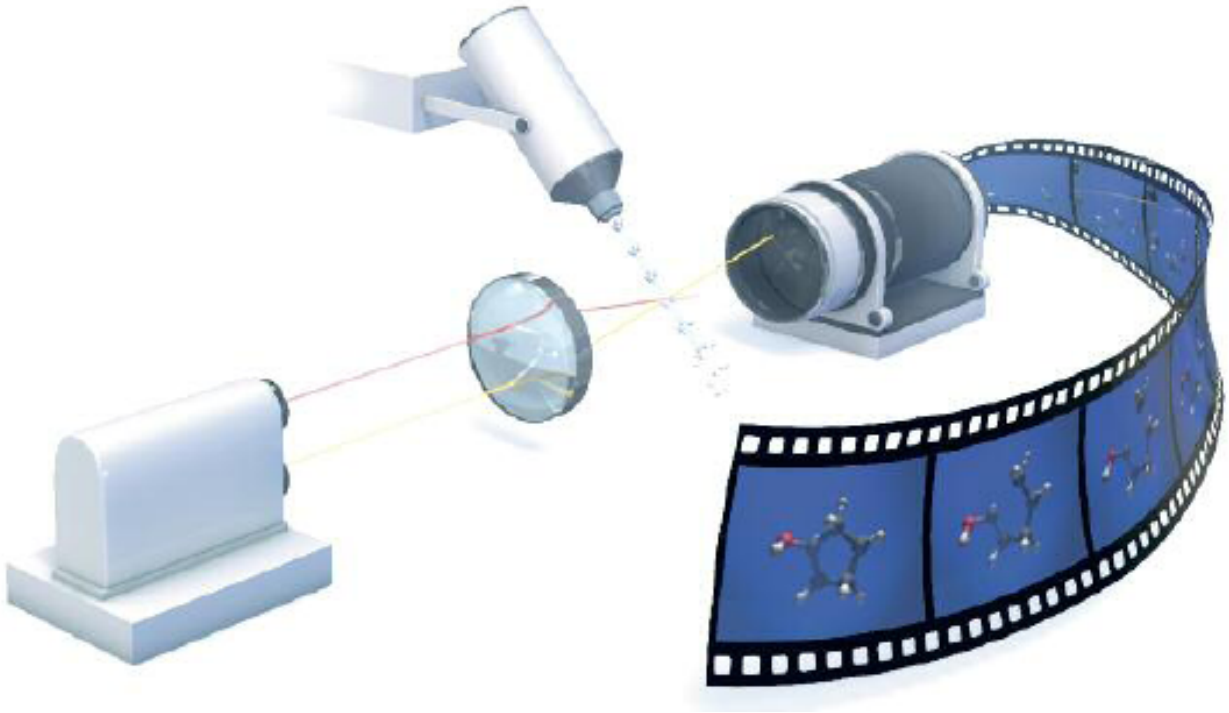
Biyoloji'de X-ışını Serbest Elektron Lazeri Deneyleri





XSEL atması bir biyomolekül ile etkileştiğinde, saçılan X-ışınları kırınım deseni oluşturur. Farklı farklı hizalanmış moleküllerden saçılan pekçok desen yardımı ile, biyomolekülün üç boyutlu yapısı belirlenir.

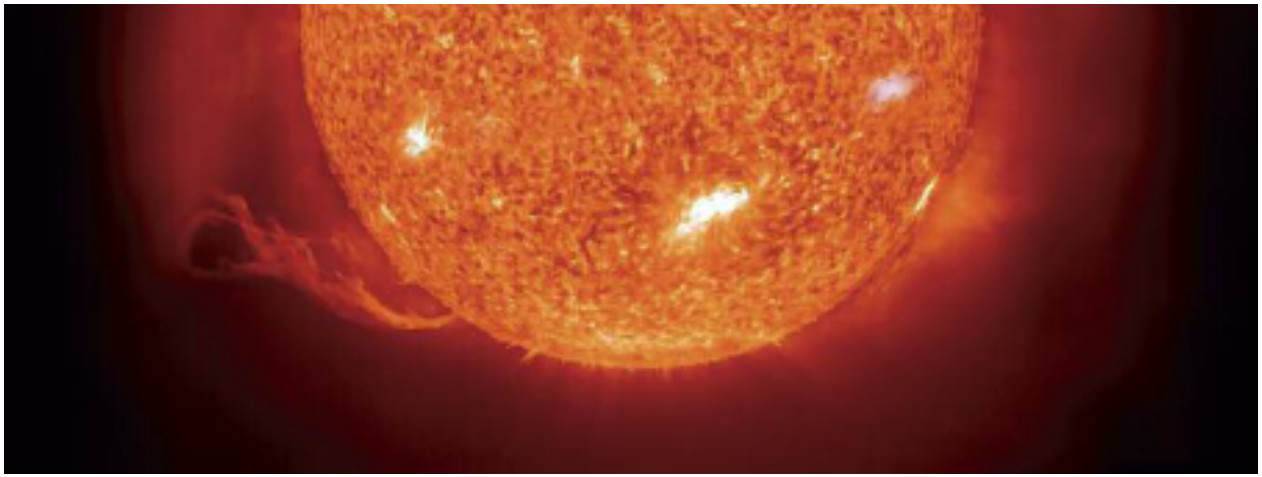
Kimya'da X-ışını Serbest Elektron Lazeri Deneyleri

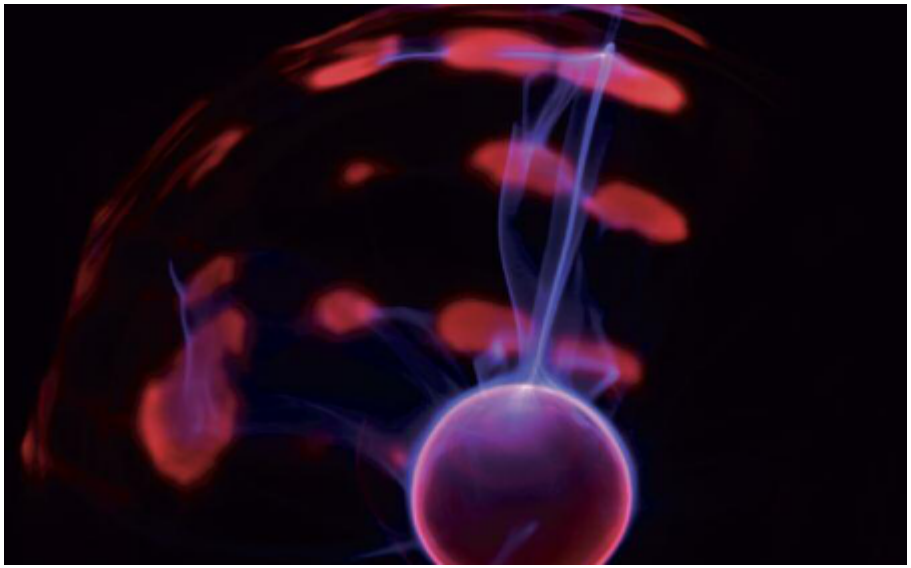


Moleküler filmler:

Bir kimyasal reaksiyon, geleneksel lazer flaşı ile tetiklenir. Ardından, molekülde oluşan değişikliklerin fotoğraf karelerini çekmek üzere, değişken zaman aralıklarıyla SEL atmaları gönderilir.

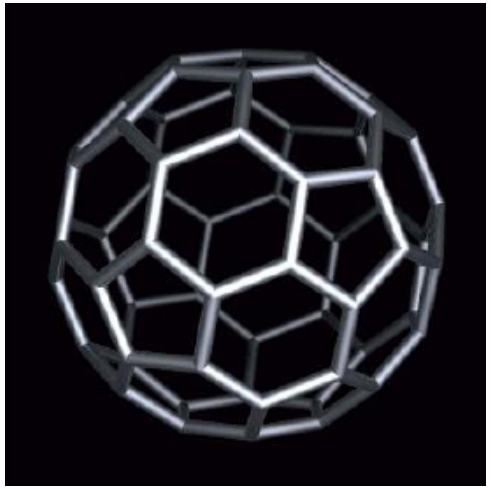
Astrofizik'te ve Sıradışı Durumlar Bilimi'nde
X-ışını Serbest Elektron Lazeri Deneyleri

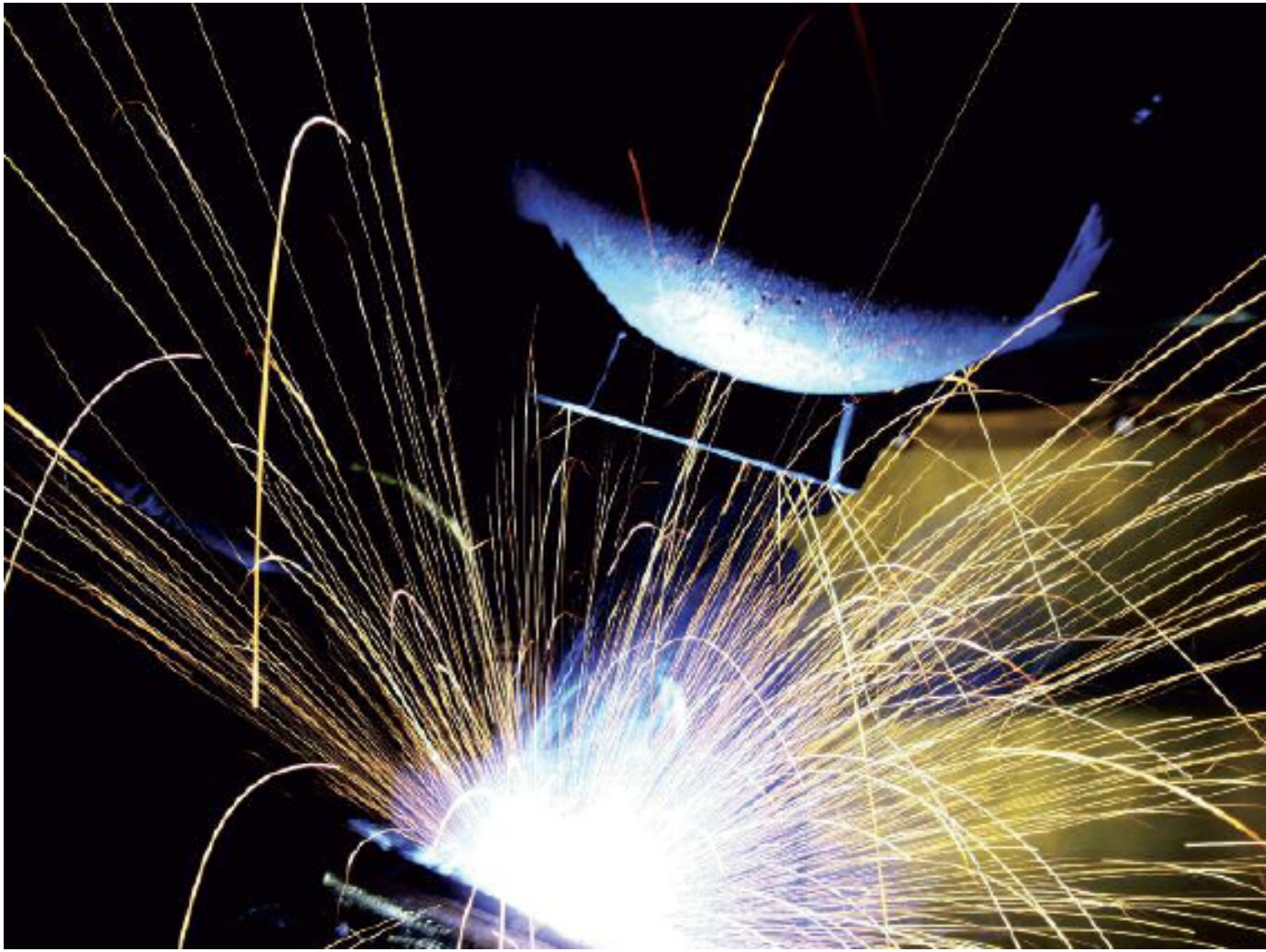




Yıldızların ve gezegenlerin plazma ve diğer sıradışı durumlarının incelenmesi

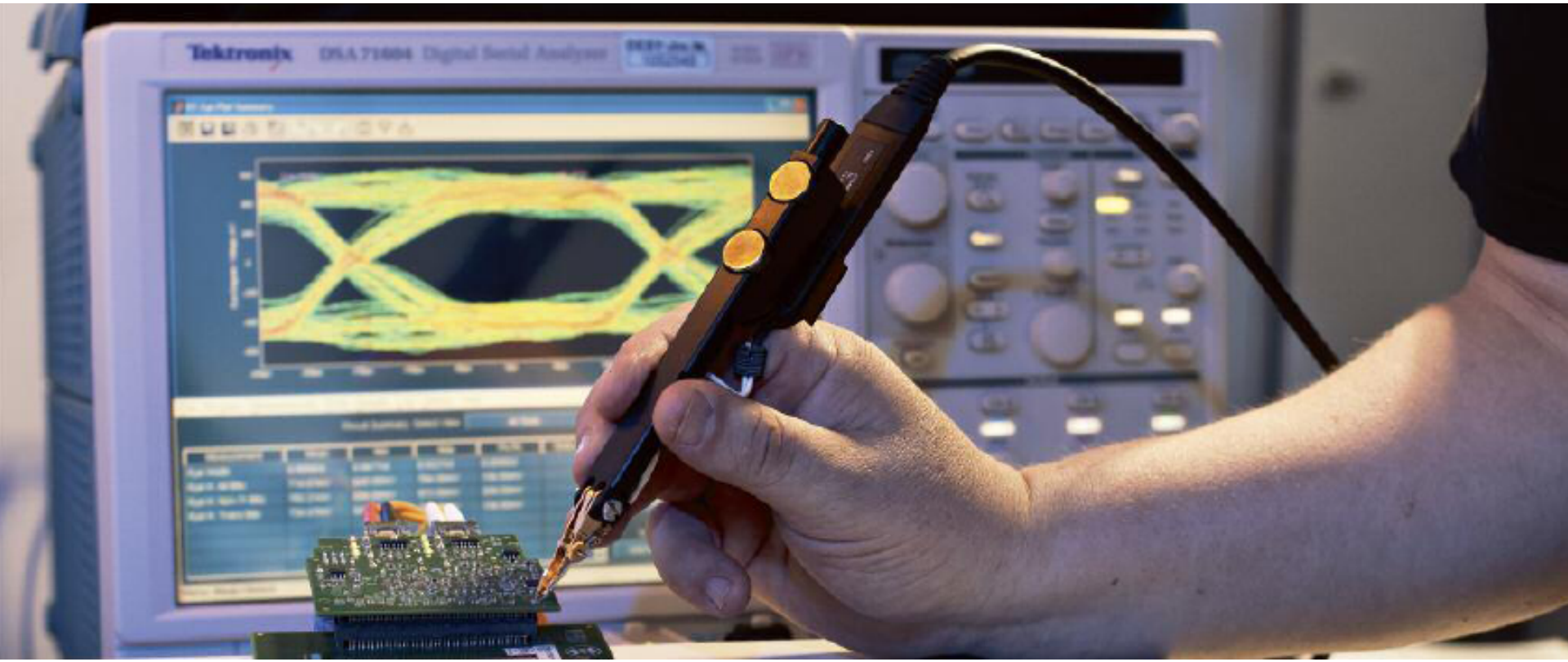
Malzeme Bilimi'nde X-ışını Serbest Elektron Lazeri Deneyleri





Uçak yapımında kullanılan kaynaklı dikişlerin kalite kontrol muayenesinde.

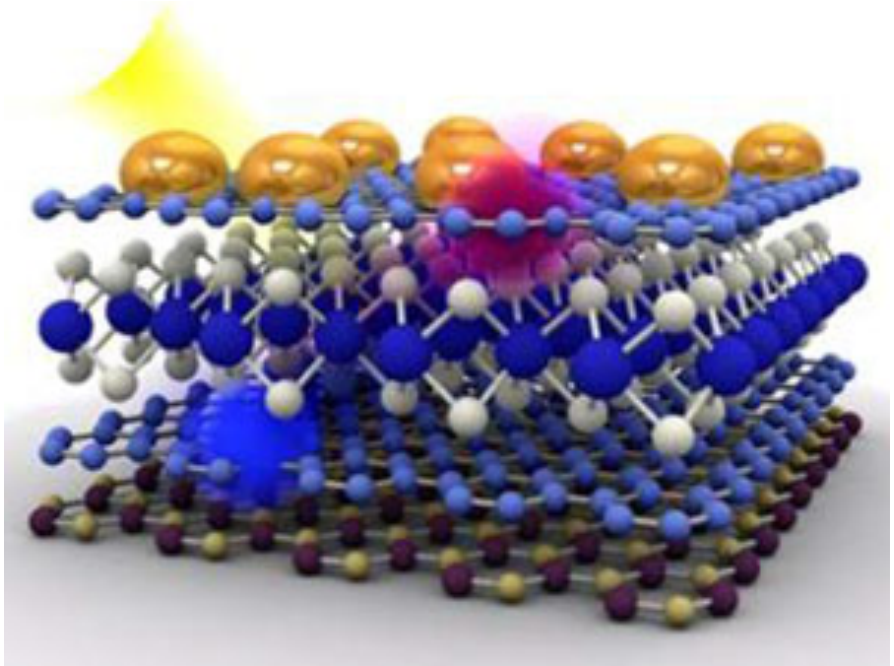
Elektronik'te X-ışını Serbest Elektron Lazeri Deneyleri



Bilgisayarların ve diğer ticari elektronik cihazların veri aktarım hızı ve depolama kapasitelerinin geliştirilmesi.

Çevre ve Enerji'de
X-ışını Serbest Elektron Lazeri Deneyleri

Güneş pillerinde meydana gelen süreçlerin atomik düzeyde çalışılması.



8 Aralık 2021

Yaşam Bilimleri Uygulamaları

Biyofizik ve Moleküler Biyoloji:

XFEL'leri Kullanarak Biyo – "Kristalografi ve Spektroskopi"

Available online at www.sciencedirect.com

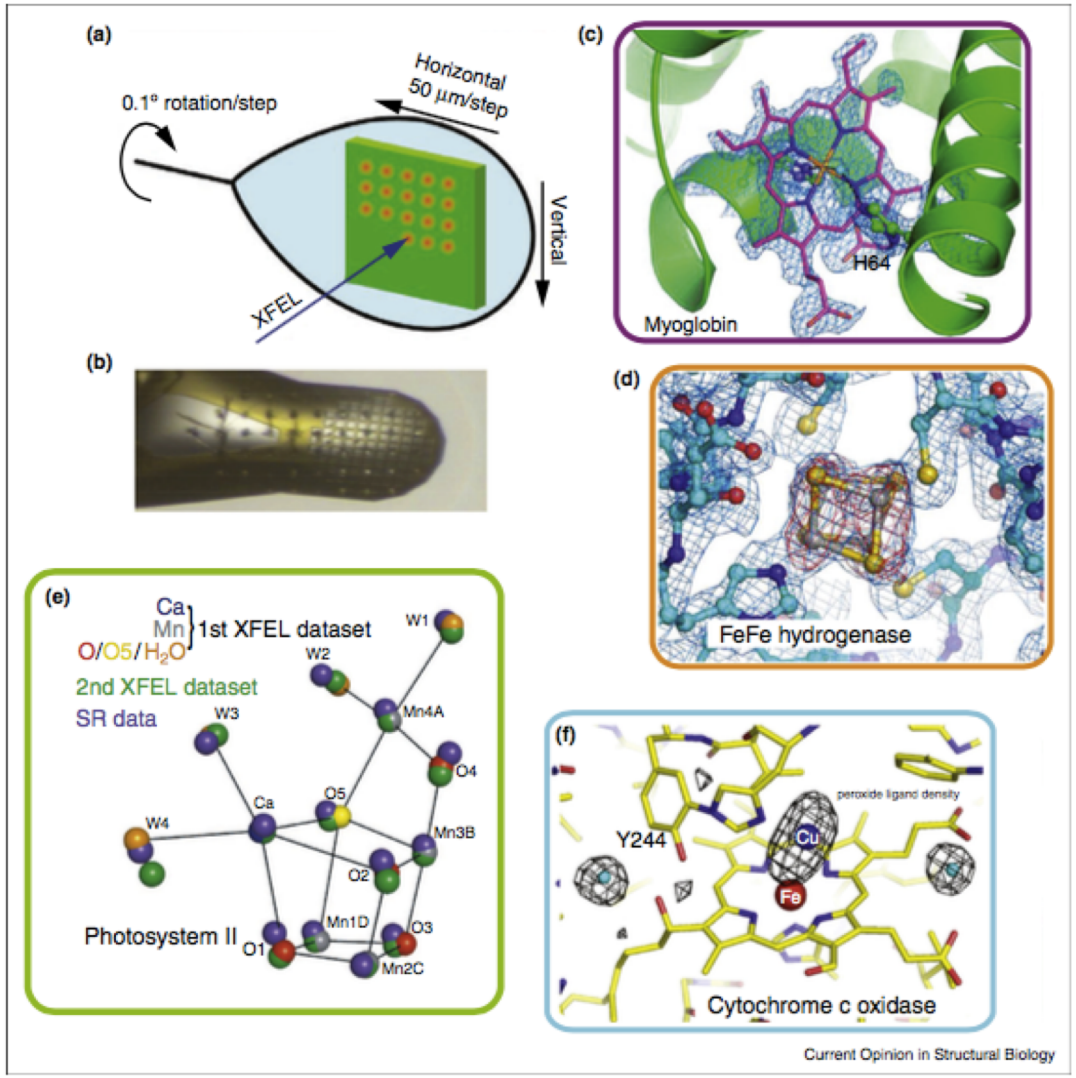
ScienceDirect

Current Opinion in Structural Biology

Metalloprotein structures at ambient conditions and in real-time: biological crystallography and spectroscopy using X-ray free electron lasers

Jan Kern[1,2], Vittal K Yachandra[1] and Junko Yano[1]

Current Opinion in Structural Biology (2015) 34, 87-98.



Goniometer based crystallography experiments of metalloenzymes at XFEL sources. **(a)** Schematic of the experimental approach using a large crystal to collect still shots in a defined orientation with respect to each other, translating by 50 μm between shots and rotating by a small angle [11••]. **(b)** Alternatively many small crystals mounted in a mesh or similarly can be used. The few μm focused beam leaves imprints on the sample [10•]. **(c)** Omit electron density for the heme group in myoglobin obtained from measuring diffraction of several hundred individual small crystals [10•]. **(d)** 2Fo – Fc (blue, contoured at 1.0σ) and Fo – Fc (red, contoured at 3.0σ) difference density maps calculated for [FeFe] hydrogenase at the site of one of the Fe–S clusters obtained from measurements on five large crystals [10•]. **(e)** Positions of the atoms in the catalytic center of PS II as obtained from cryo SFX is shown in comparison to the positions obtained by SR experiments (blue spheres) [9••]. **(f)** Radiation damage free omit map for the FeCu center of CoC showing the position of the peroxide ligand [11••].

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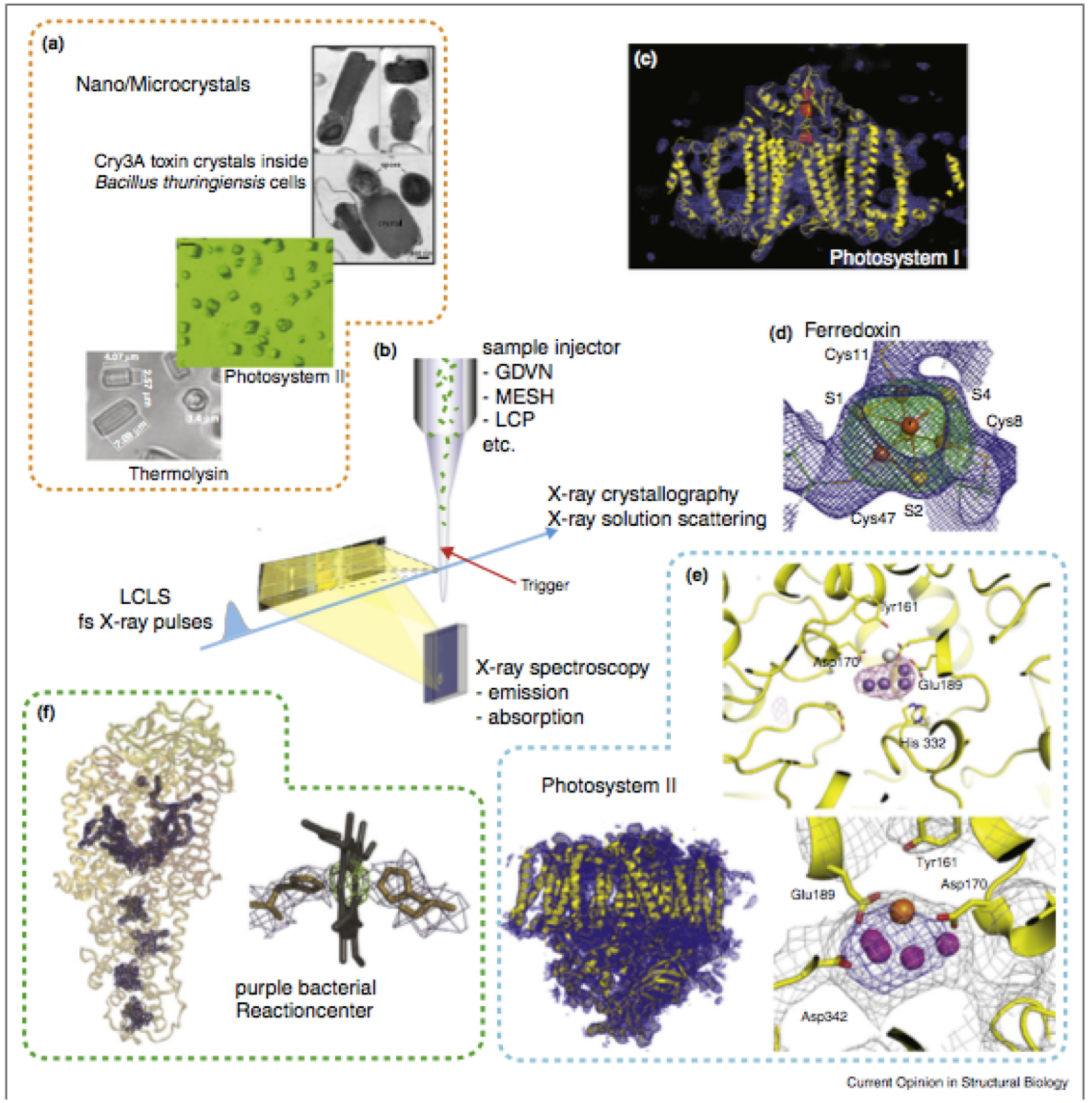
e) Fotosistem II'nin katalitik merkezlerindeki atomların pozisyonları.

Mavi küreler SR deneylerinden elde edilen pozisyonları, diğer renkler ise cryo-Serial Femtosecond Crystallography (SFX) pozisyonlarını temsil etmektedir.

b) Liquid Jet

düzeneği ile forward scattering şematik olarak gösterilmiştir.

Bu düzenek, tetiklemeli optik lazer atmaları ve spektroskopik ölçümlerle birleştirilebilir (örneğin, X-ray Emission Spectroscopy gibi).



Jet based crystallography experiments of metalloenzymes at XFEL sources. **(a)** Examples of nano- to micrometer size crystals used, e.g. thermolysin [17], PS II [36••] and toxin crystals (grown inside cells) [29]. **(b)** Schematic of the experimental approach using a liquid jet for sample delivery to the interaction point and collecting the forward scattering is shown. This setup can be combined with triggering by optical laser pulses and with spectroscopic measurements, e.g. X-ray emission spectroscopy. XFEL structures obtained: **(c)** PS I with electron density shown in blue and omit maps for the Fe_4S_4 clusters in red [25]. **(d)** Electron density for one of the Fe_4S_4 clusters in ferredoxin, with omit map shown in green [32]. **(e)** PS II with overall structure of one monomer (bottom left), the oxygen evolving complex (bottom right) [36••] and the anomalous difference density from the Mn atoms in the OEC (top right) [31•]. **(f)** PBRC with overall structure and omit maps for the cofactors (left) and detail for the electron density obtained for one of the heme groups (right) [33].

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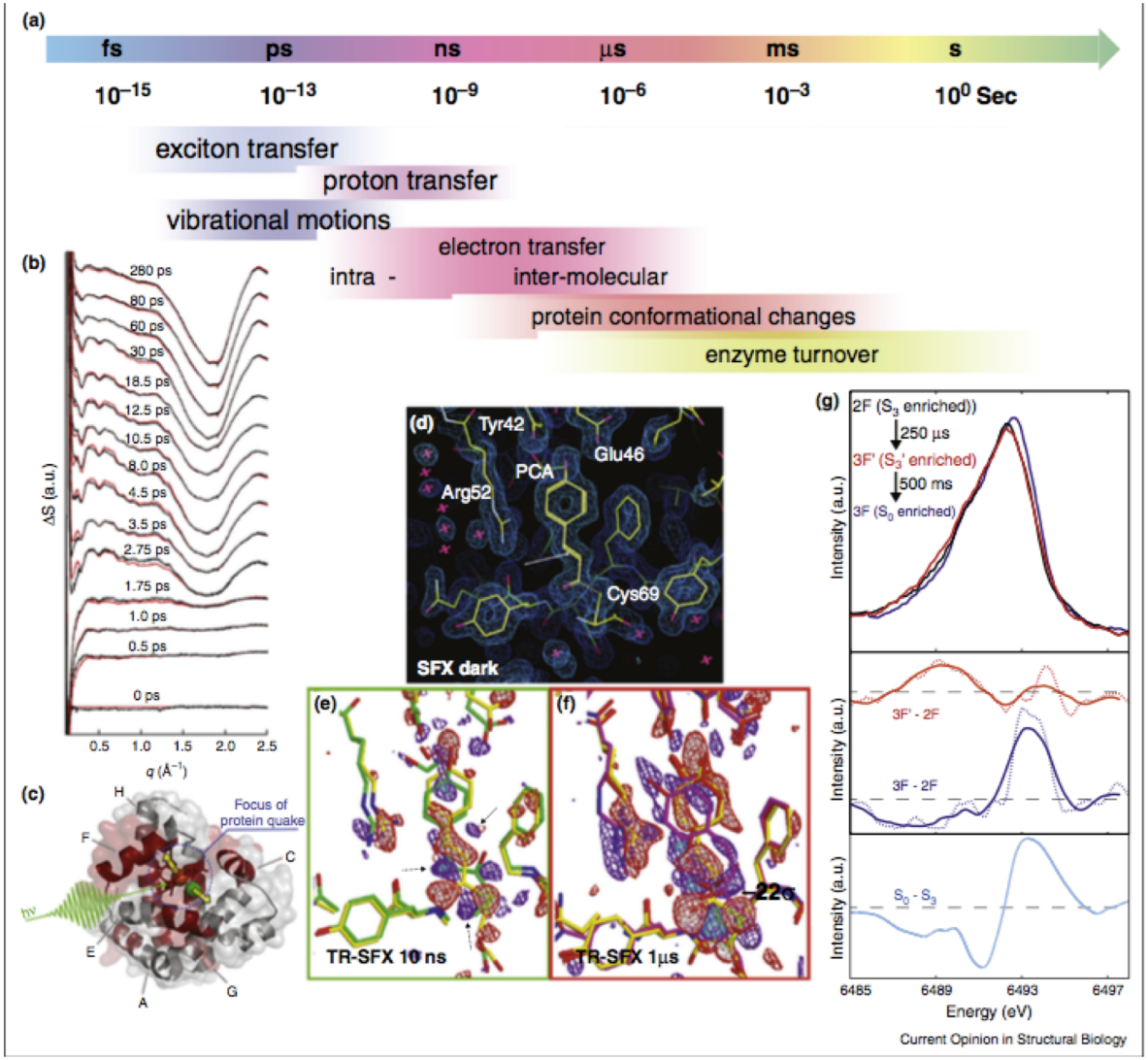

Time resolved experiments using fs X-ray pulses at the CXI instrument at LCLS. **(a)** Timescales for dynamic processes in proteins/enzymes. **(b)** Time resolved WAXS measurements on the photosynthetic bacterial reaction center. Upon light excitation a ultrafast protein movements in the ps time regime was visible [44*]. **(c)** Illustration of the protein-quake observed within a few ps in myoglobin upon photodissociation of CO [45*], red shaded areas are involved in the movement leading to a volume increase of ~200 Å^3. Time resolved serial femtosecond crystallography on photoactive yellow protein, showing the electron density for **(d)** the dark state as well as difference electron density for **(e)** data recorded 10 ns after light excitation and **(f)** 1 µs after light excitation. A movement of the S-atom of the chromophore is visible already in the 10 ns data (Adapted from [46]). **(g)** X-ray emission spectra of Mn in photosystem II. Spectra are shown for the 2F state (S_3), as well as for a intermediate 250 µs after the 3rd light flash and 0.5 s after the 3rd light flash (S_0-state). The difference spectra (middle panel) indicate a reduction in the S_3-S_0 transition (as expected from SR measurements — bottom panel), but no specific reduction is visible for the 250 µs state [31*].

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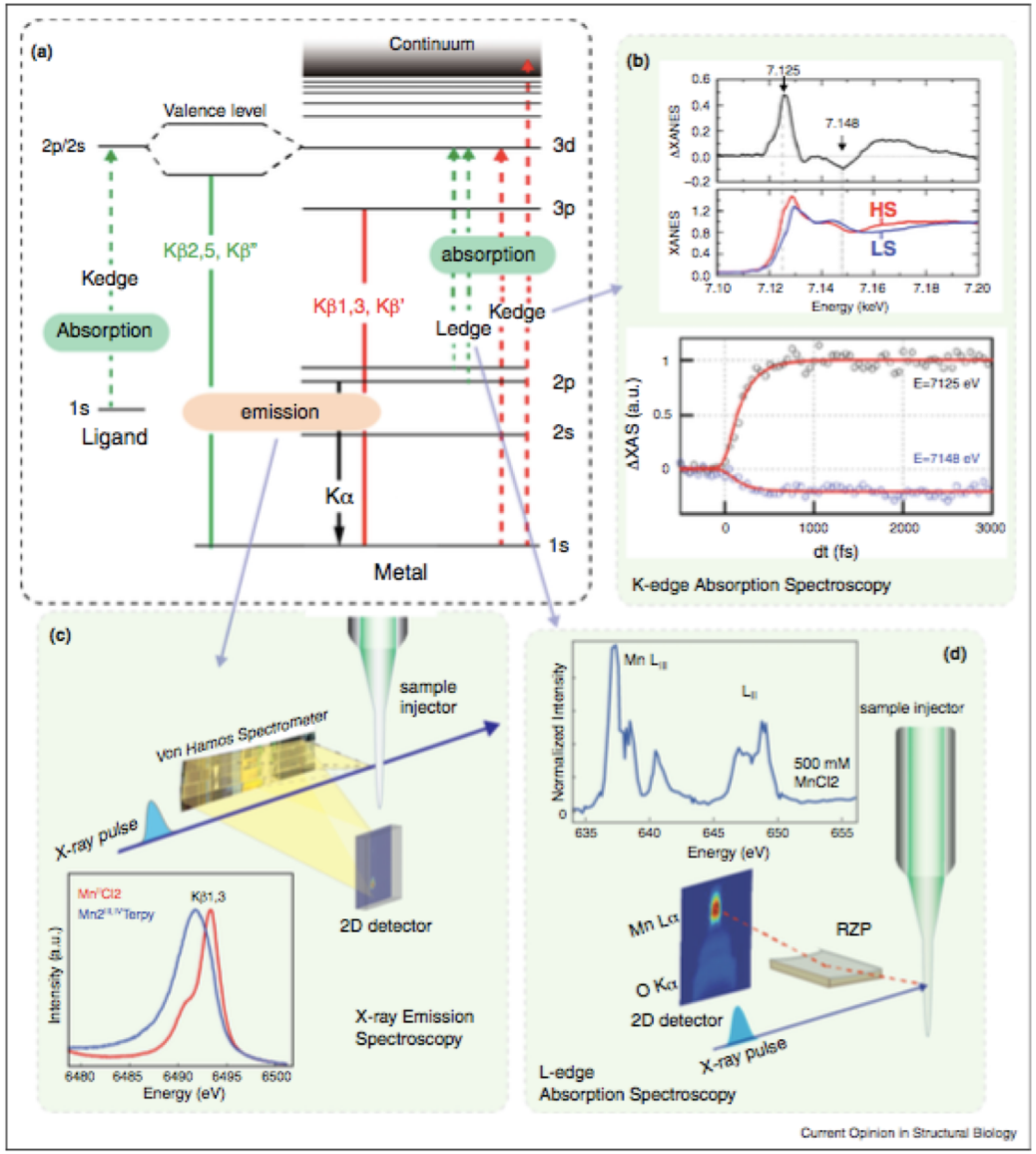
a) Proteinlerdeki ve enzimlerdeki dinamik süreçler için zaman mertebeleri

Titreşimsel hareketler ve exciton transferleri için femtosecond deneyler gerekli.

c) Mn2 ve MnCl2 1s-3p orbitalleri arasındaki "K_β emission" enerjileri için Von Hamos Spectrometer



X-ray spectroscopic measurements using XFEL pulses. **(a)** Energy level diagram illustrating the transitions involved in L- and K-edge transition metal spectroscopy. **(b)** Examples for Fe K-edge absorption spectra showing transient changes in spin state [53]. **(c)** Experimental setup for collecting Kβ emission spectra using a dispersive Von Hamos spectrometer and a sample injector. In addition spectra of two Mn compounds collected at LCLS are shown [51]. **(d)** Experimental setup for collection of Mn L-edge spectra at an XFEL from dilute aqueous solutions of Mn compounds using a reflective zone plate (RZP) spectrometer. The spectrum shown was recorded at LCLS using 500 mM $MnCl_2$ in water [56•].

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Yüksek Teknoloji Uygulamaları

Doğadaki Çok Hızlı Süreçlerin İncelenmesi

- Charge transfer in catalytic/photovoltaic systems – 1 fs and longer
- Phase change in materials – 2 fs and longer
- Ultrafast spintronics – fs and longer
- Control electron-ion motions in chemical reactions – 1 fs and longer
- X-ray induced processes – 50 as and longer
- Strong field physics – zeptoseconds and longer

} Electron dynamics

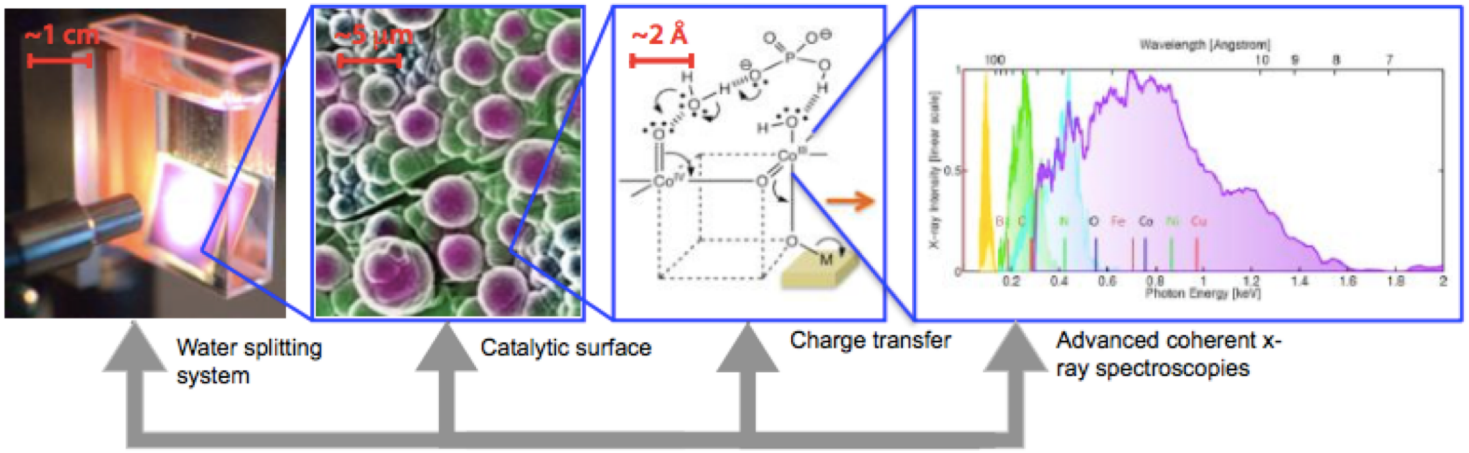
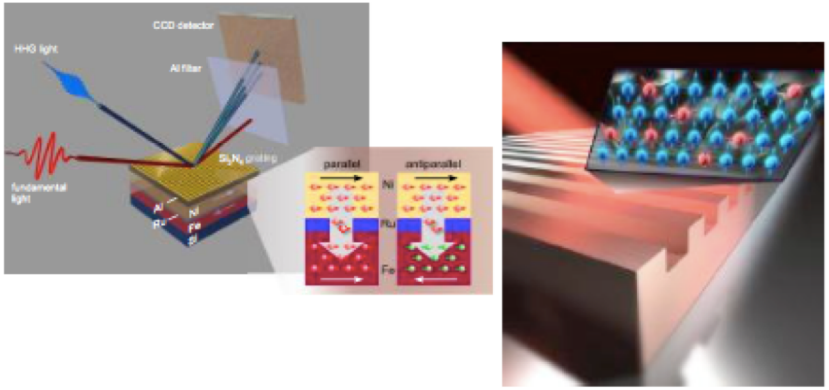
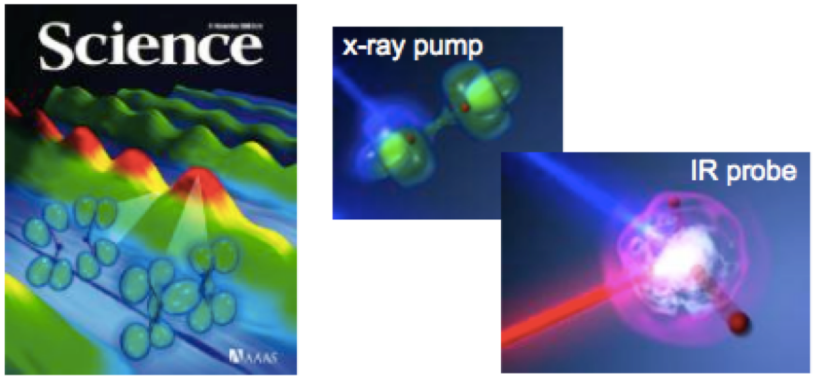


Image charge transfer in complex systems relevant to energy, catalysis using coherent x-ray spectroscopy spanning many elemental absorption edges simultaneously

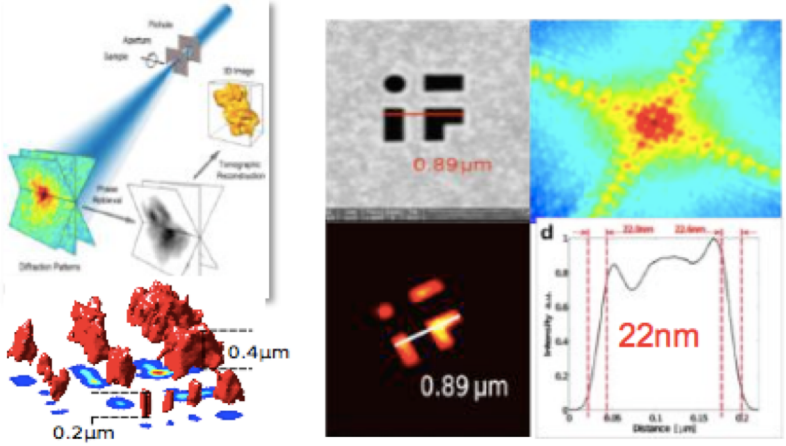
Yüksek Harmoniklerle Nanodinamiklerin Görüntülenmesi



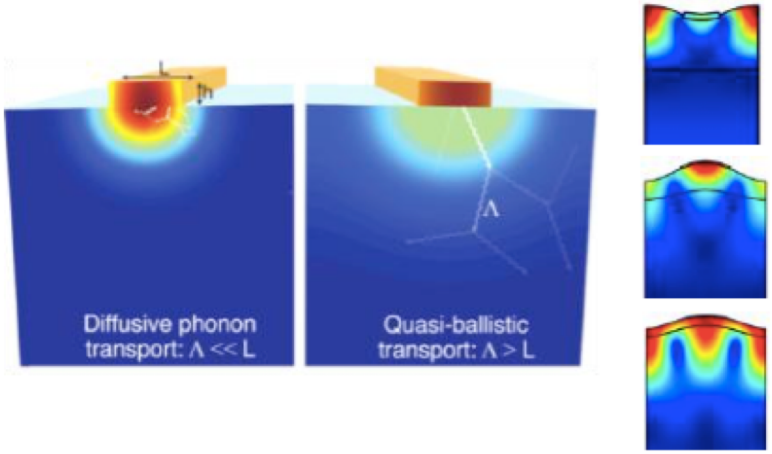
Capture charge-spin-phonon dynamics at multiple sites: *(Nature **471**, 490 (2011), PNAS **109**, 4792 (2012); Nature Comm **3**, 1037 (2012); Nature Comm **3**, 1069 (2012))*



Coupled electron-nuclear dynamics in molecules: *(Science **317**, 1374 (2007), Science **322**, 1081 (2008), Nature Phys. **8**, 232 (2012), PRL **109** , 073004 (2012))*

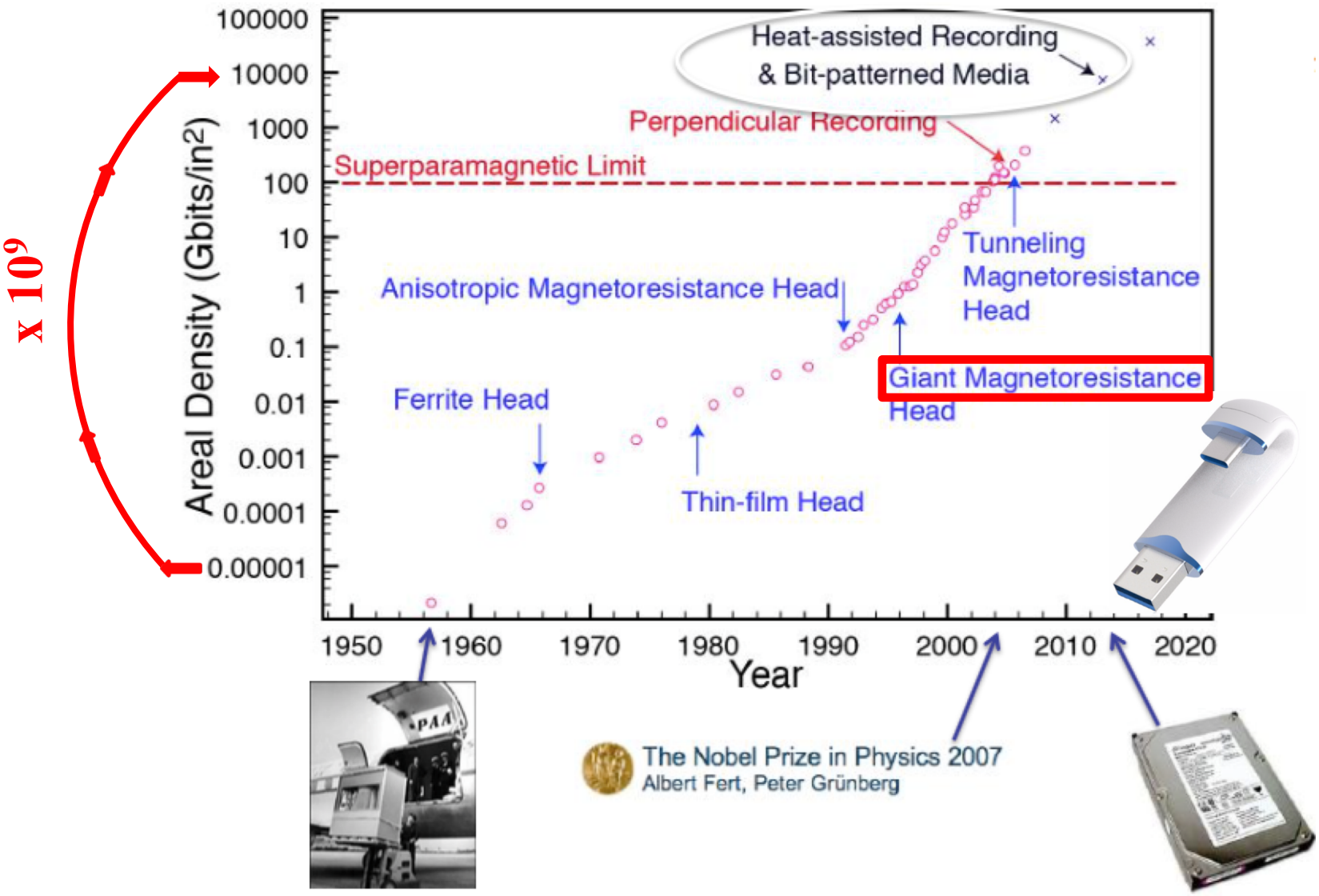


Nanoscale imaging: Record tabletop 22nm resolution *(Op. Ex. **19**, 22470 ('11); **17**, 19050 ('12); Nature **463**, 214 (2010))*



Nanoscale energy transport: probe nanoscale energy/strain flow *(Nature Materials **9**, 26 (2010); Nano Letters **11**, 4126 (2011); PRB **85**, 195431 (2012))*

20. Yüzyılın İkinci Yarısından Günümüze Veri Depolama Evrimi



The Nobel Prize in Physics 2007

"for the discovery of Giant Magnetoresistance"

Photo: U. Montan

Albert Fert

Photo: U. Montan

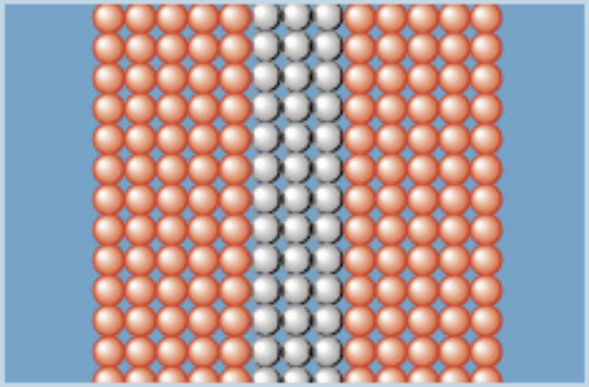
Peter Grünberg

The Nobel Prize in Physics 2007

*This year's Nobel Prize in Physics is awarded to **ALBERT FERT** and **PETER GRÜNBERG** for their discovery of Giant Magnetoresistance. Applications of this phenomenon have revolutionized techniques for retrieving data from hard disks. The discovery also plays a major role in various magnetic sensors as well as for the development of a new generation of electronics. The use of Giant Magnetoresistance can be regarded as one of the first major applications of nanotechnology.*

Better read-out heads for pocket-size devices

Constantly diminishing electronics have become a matter of course in today's IT-world. The yearly addition to the market of ever more powerful and lighter computers is something we have all started to take for granted. In particular, hard disks have shrunk – the bulky box under your desk will soon be history when the same amount of data can just as easily be stored in a slender laptop. And with a music player in the pocket of each and everyone, few still stop to think about how many cds' worth of music its tiny hard disk can actually hold. Recently, the maximum storage capacity of hard disks for home use has soared to a terabyte (a thousand billion bytes).



A nanometre is one millionth of a millimetre and corresponds to only a few layers of atoms. Albert Fert's and Peter Grünberg's original structures for giant magnetoresistance consisted of only a few layers of atoms of magnetic iron (red) sandwiched with chromium (grey).

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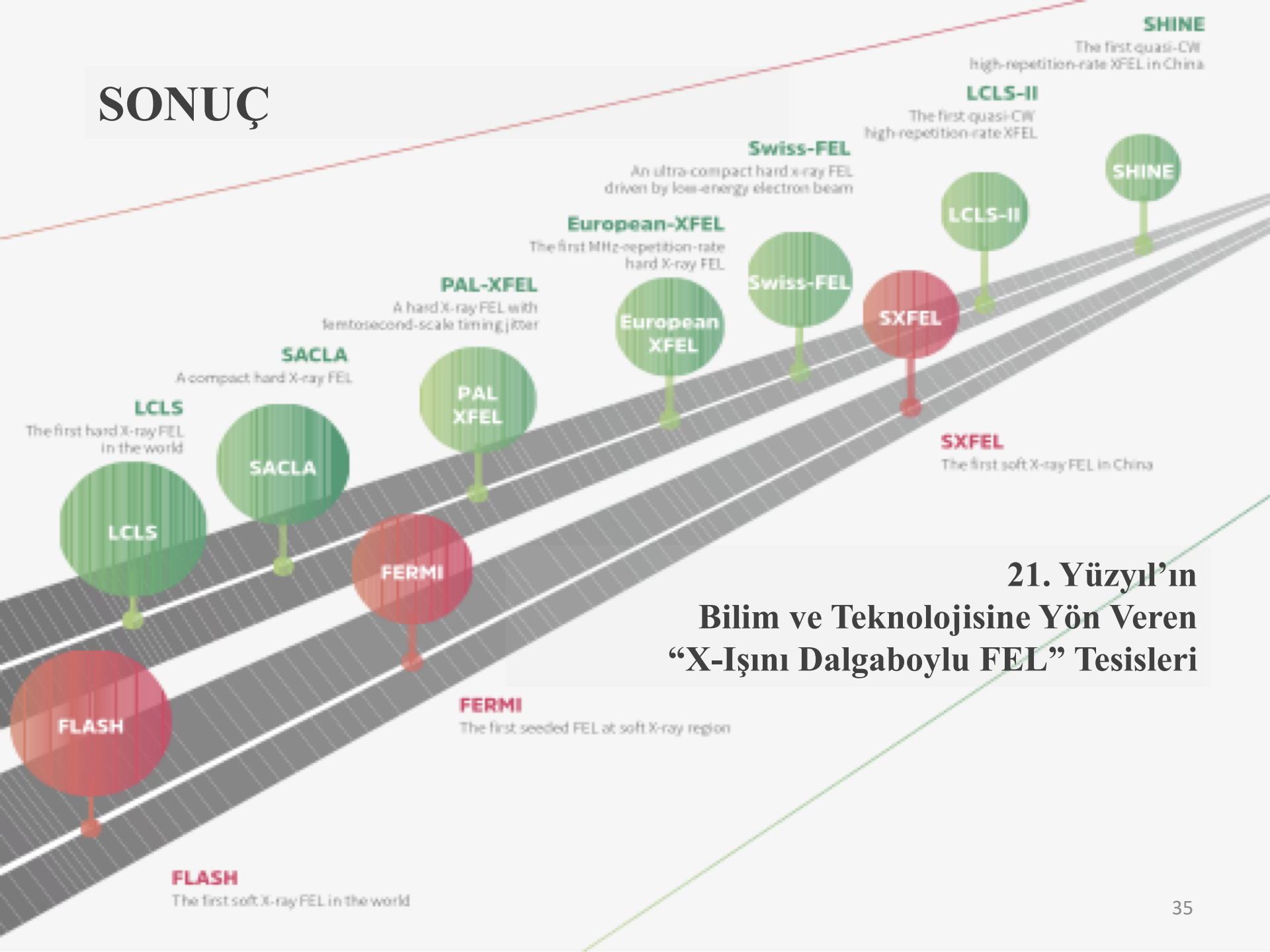

21. Yüzyıl'ın
Bilim ve Teknolojisine Yön Veren
"X-Işını Dalgaboylu FEL" Tesisleri

İlginiz ve Katılımınız için Teşekkür Ederim.