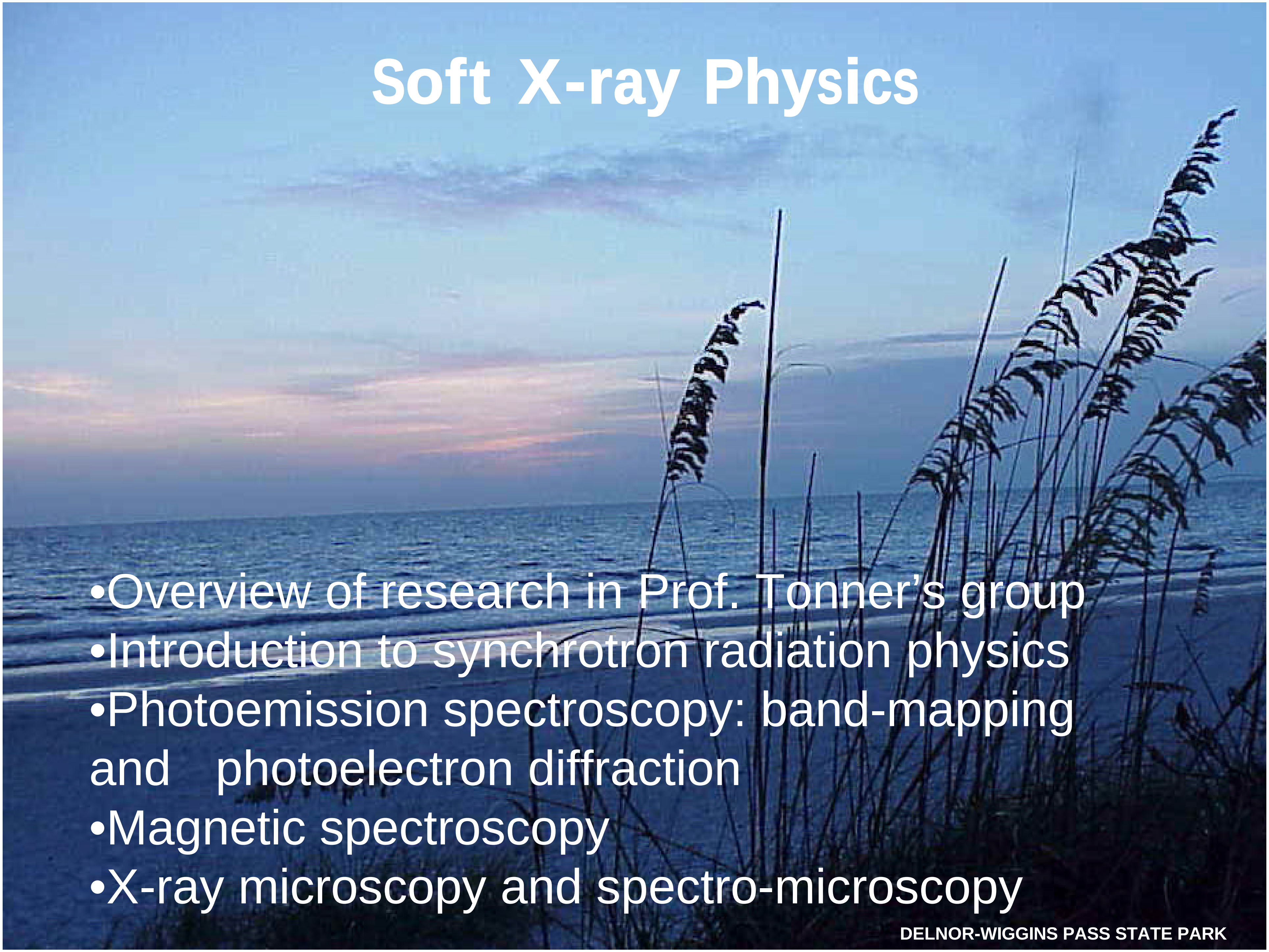

Soft X-ray Physics

- Overview of research in Prof. Tonner's group
- Introduction to synchrotron radiation physics
- Photoemission spectroscopy: band-mapping and photoelectron diffraction
- Magnetic spectroscopy
- X-ray microscopy and spectro-microscopy

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Research Projects in Brian Tonner's Group

Magnetic Nanostructures

Biophysical Processes in the Environment

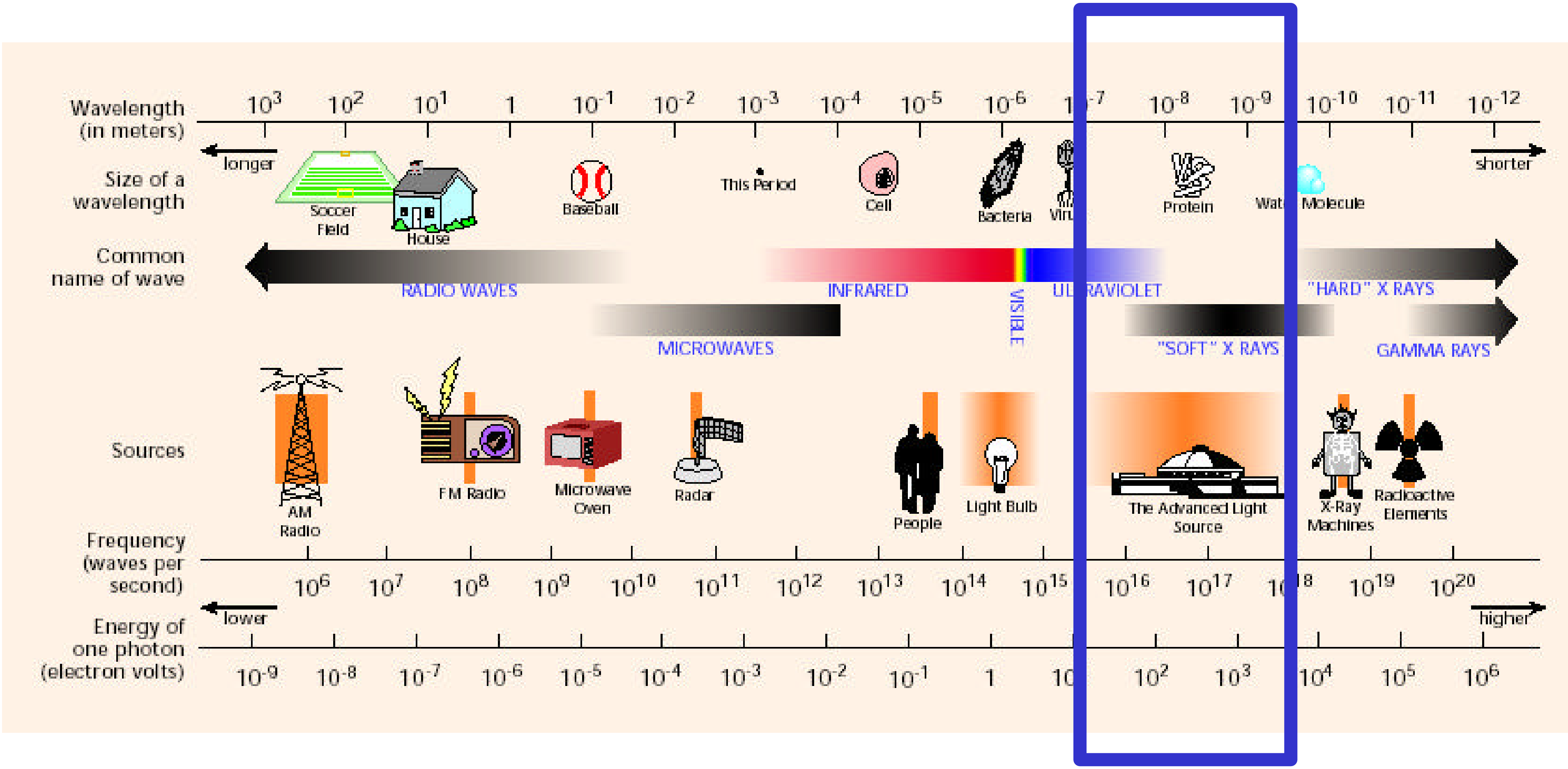
Soft X-ray Spectroscopy

Atomic structure of surfaces and interfaces

Biogenic Materials (Bio-nanostructures)

X-ray Absorption Spectroscopy (XAS), X-ray Photoelectron Spectroscopy (XPS), X-ray Photoelectron Diffraction (XPD), X-ray Magnetic Circular Dichroism (XMCD)

The Soft X-ray Spectrum



Lower Bound: VUV cut-off of absorption in Quartz (about 10 eV) [200nm or 6 eV]
Upper Bound: Absorption edges of light solids, like Be (about 2000 eV).

What makes Soft X-ray Science Important?

- The photon energy exceeds the work function of most materials, so electrons can be removed from the sample

- The photon energy matches the binding energy of the “shallow core-levels” of atoms, which are the narrowest lines with the most chemical information

- It is possible to create beams of soft x-rays with very high coherence, allowing us to do sophisticated x-ray interference experiments

$$\hbar w \geq e\Phi \qquad \hbar w \approx eV_B \qquad l \geq a \cdot \Delta\Theta$$

What makes development of Soft X-ray Science so difficult?

- Sources of radiation were weak, until introduction of synchrotron radiation in early 1970’s
- Strong absorption by air requires the use of vacuum beamlines
- Low reflectivity of metals in soft x-ray region (high absorption) means new methods of optics had to be developed

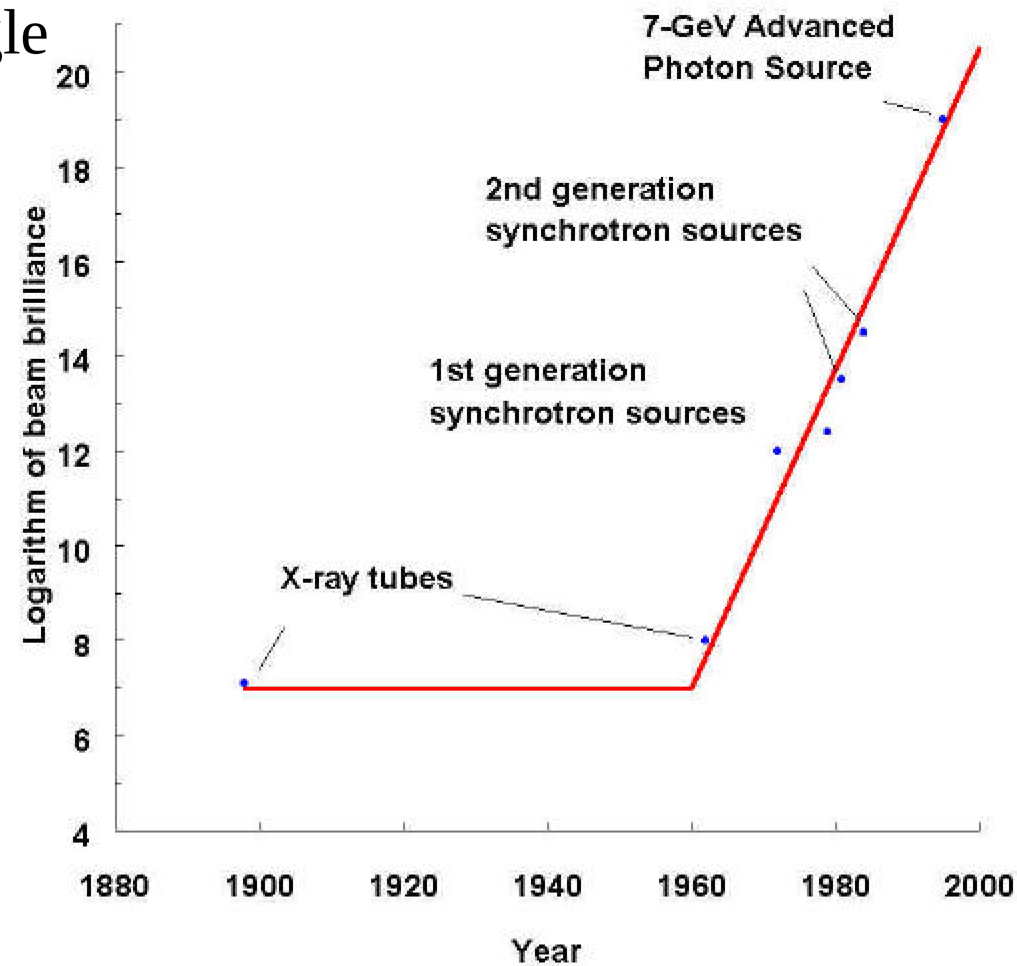
The growth of synchrotron light sources

Brilliance/brightness:
Photons/time/area/solid-angle

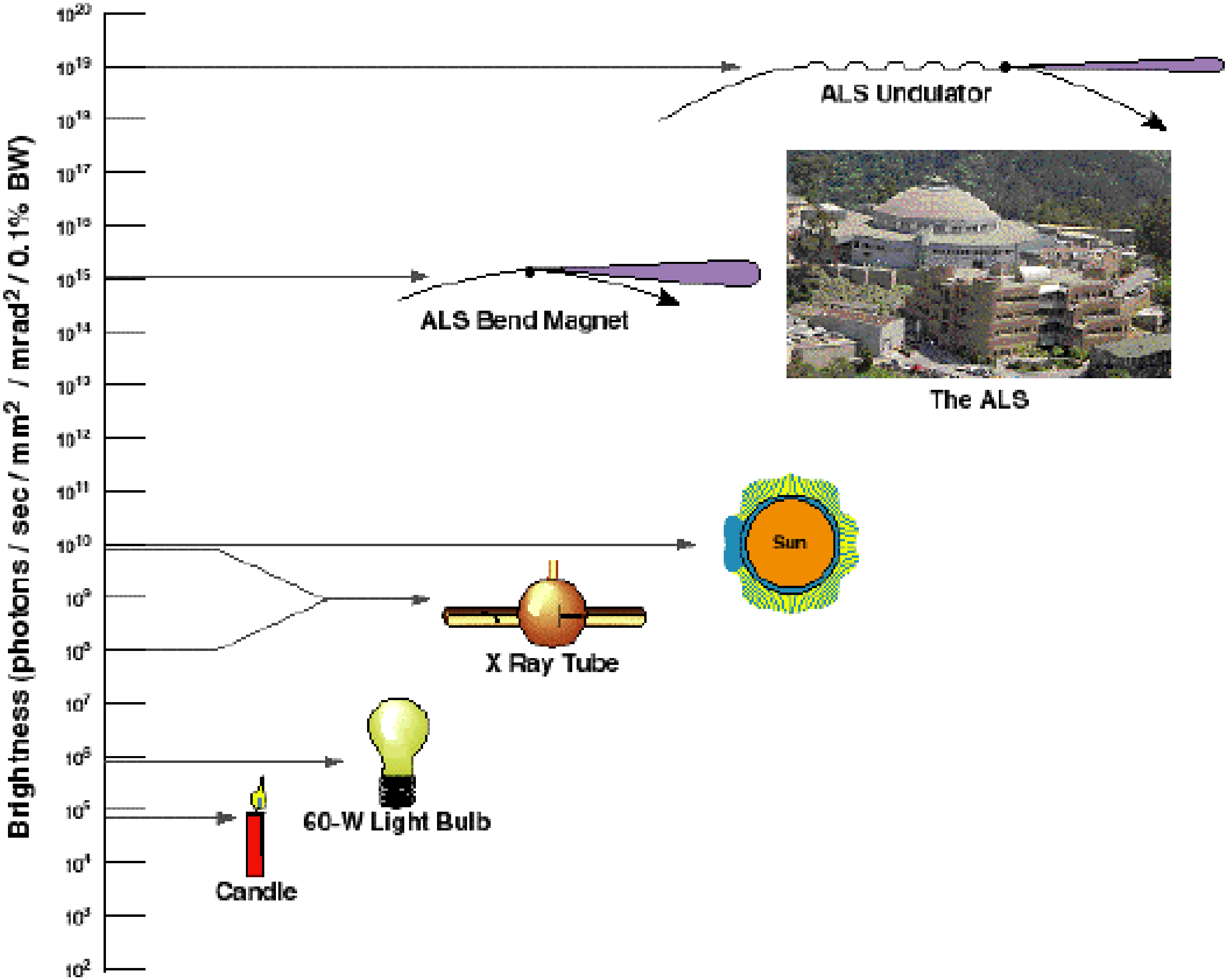
Brilliance (brightness) is determined by the emittance of the stored beam in the synchrotron. The emittance is the product of the particle beam cross-sectional area and the angular divergence of the particle beam. It is a few nanometers in modern 3rd generation machines.

Flux:
Photons/time/area

Flux is determined by the optical system that delivers light to the sample. It is often the parameter most important to the experiment. Because of the limitations of optics, not all light can be collected—only that in a narrow cone of angles. Because of this, FLUX usually scales with BRIGHTNESS.



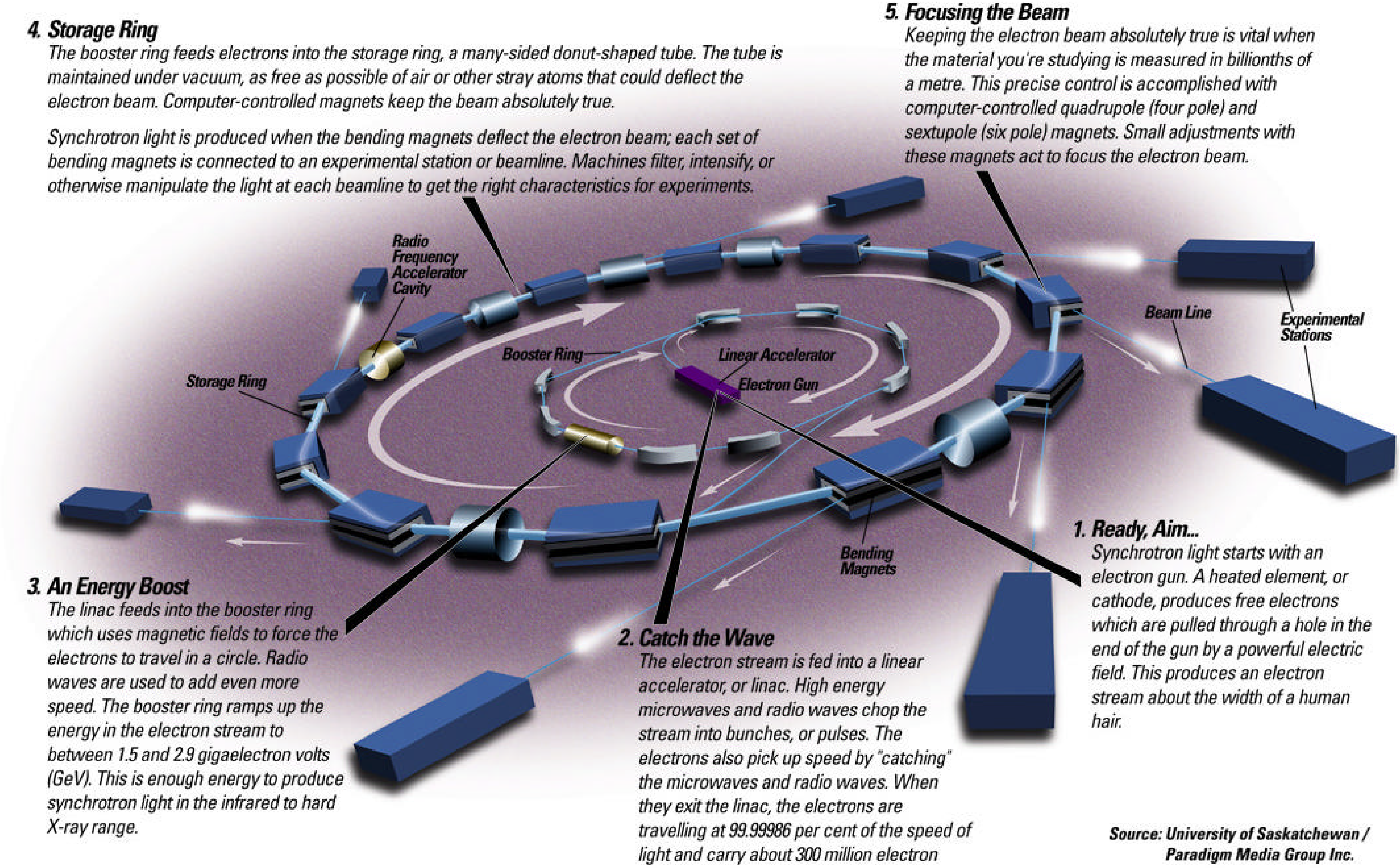
Brightness of various sources



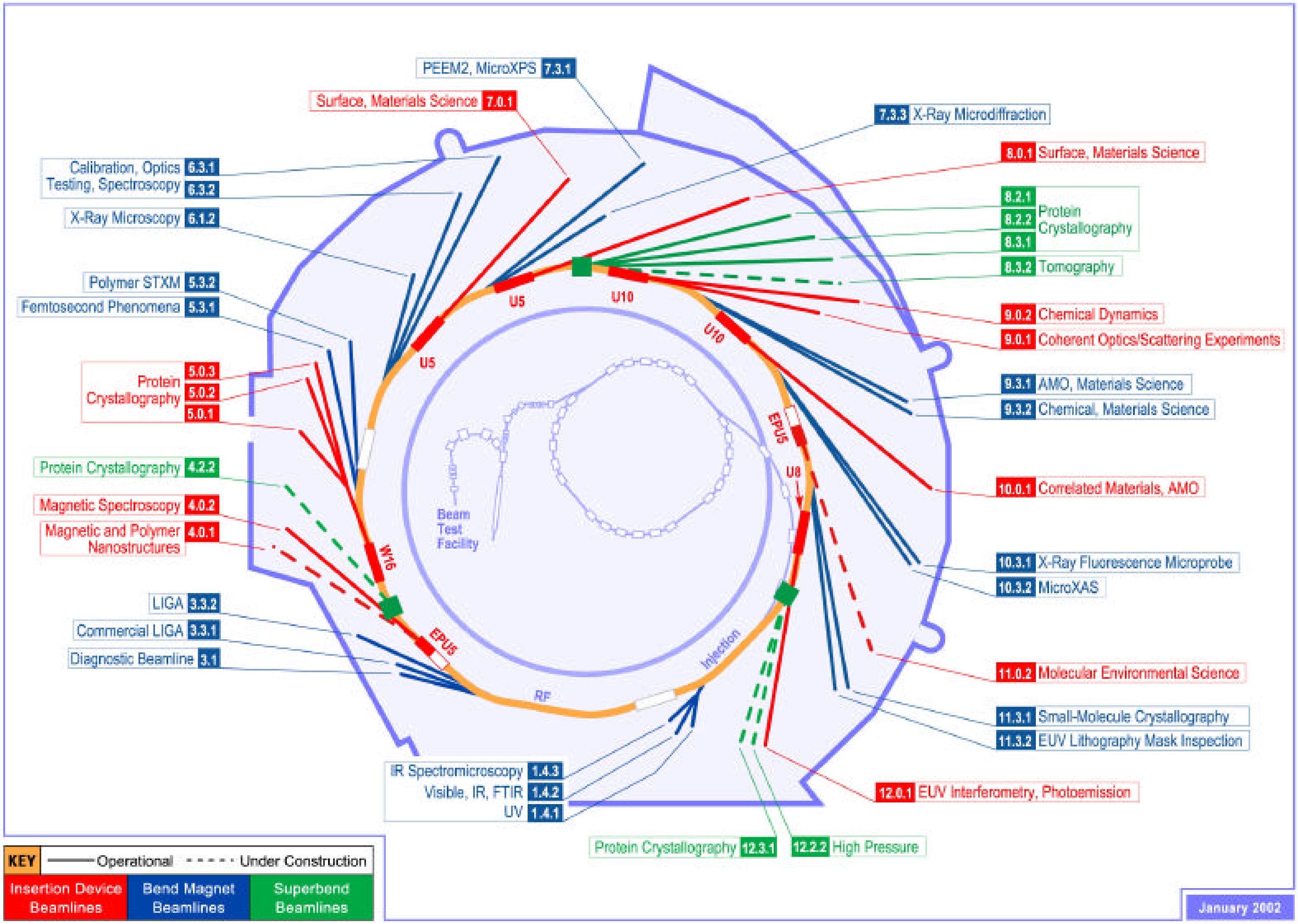
Synchrotron facilities are flexible soft x-ray sources

The Advanced Light Source at Lawrence Berkeley Lab

Facility layout of a synchrotron

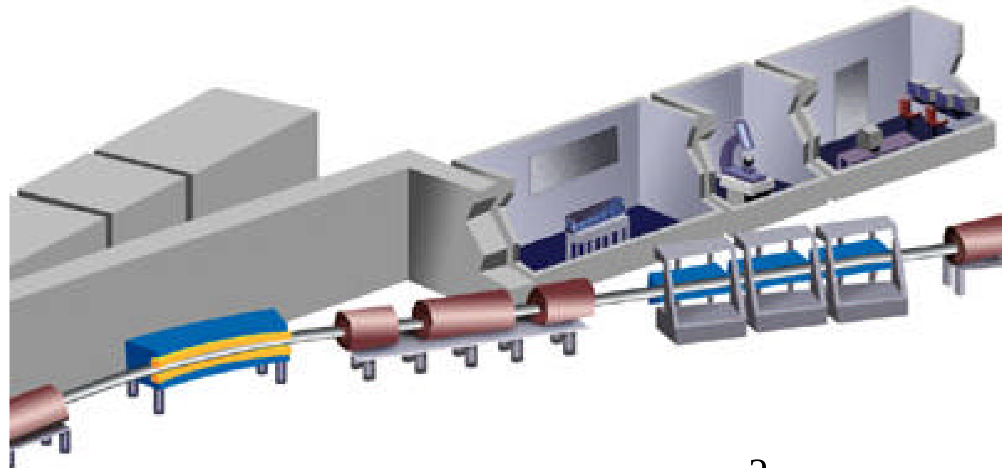


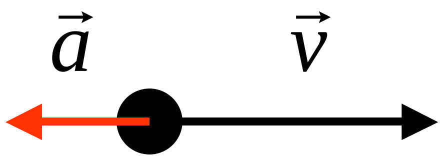
ALS beamlines



Production of Synchrotron Radiation

Synchrotron radiation is the electromagnetic radiation produced when a charged particle is subjected to a *time-varying* acceleration. It is significant only at highly relativistic velocities. Because it leads to a loss of power in a relativistic particle beam, it was originally considered “waste radiation”. Linear accelerators are designed to minimize the production of synchrotron radiation.

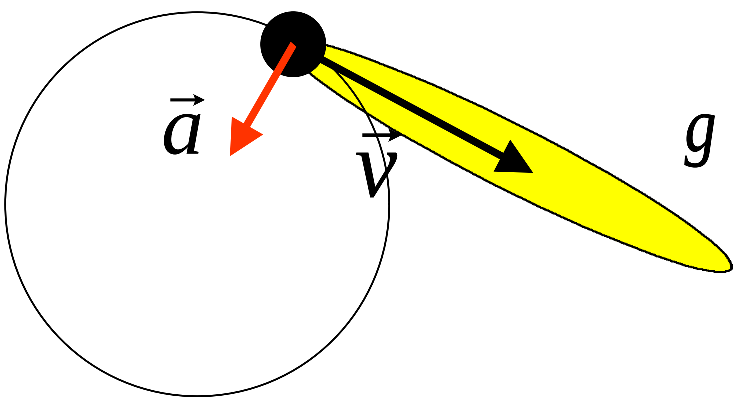




No synchrotron radiation. Brehmstrahlung (braking radiation) is small as v approaches c.

$$P = \frac{2}{3}\frac{e^2}{c^3}\left|\dot{v}\right|^2$$

Synchrotron radiation focussed in forward direction. The time rate of change of the velocity does not vanish as v approaches c.

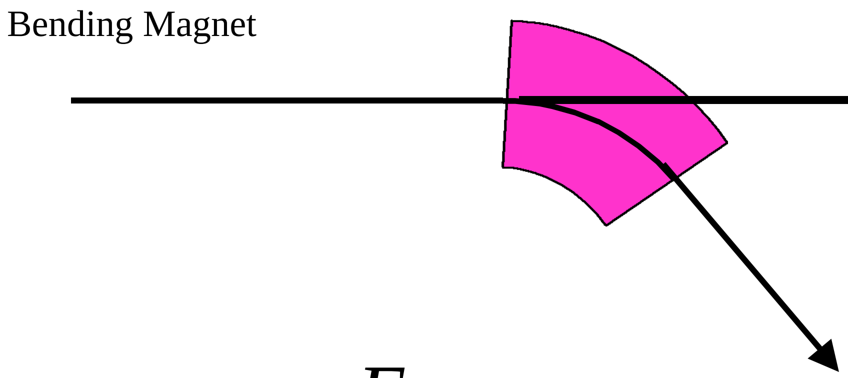


$$\gamma = \frac{E}{m_0 c^2}$$

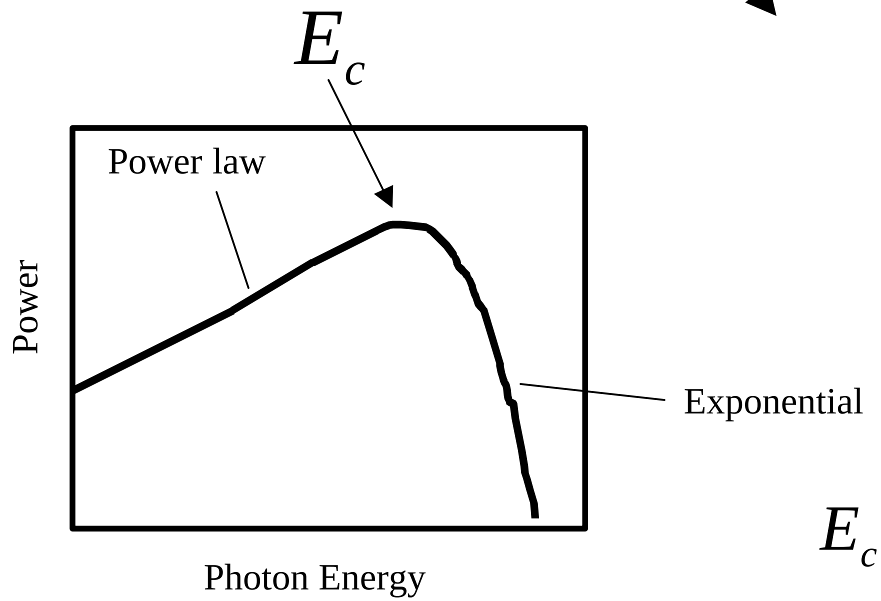
At 1 GeV, γ is about 2000.

$$\Delta\Theta \approx \frac{1}{\gamma}$$

Types of synchrotron radiation sources: Bending magnets



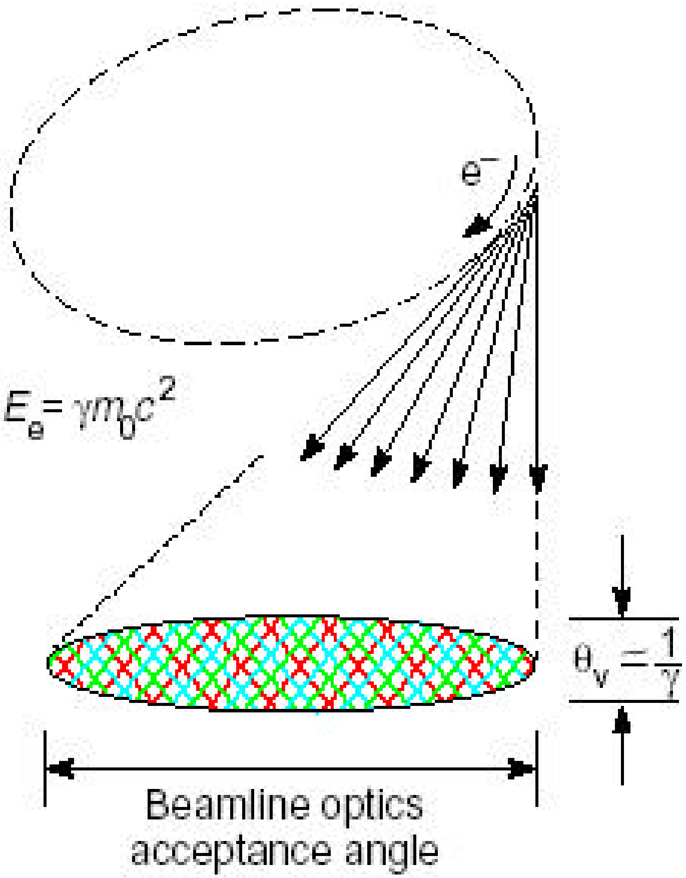
Large horizontal divergence.
Vertical divergence 1/γ.
Broad energy spectrum.

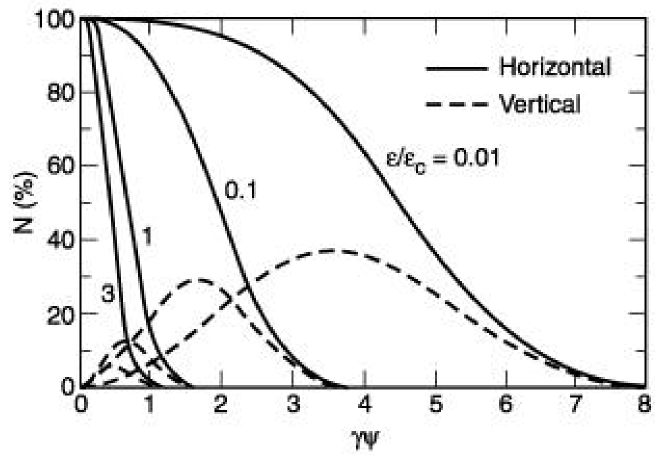


The critical energy is determined by the kinetic energy of the stored beam, and the strength of the magnetic deflection field.

$$E_c[keV] = 0.665E^2[GeV]B[T]$$

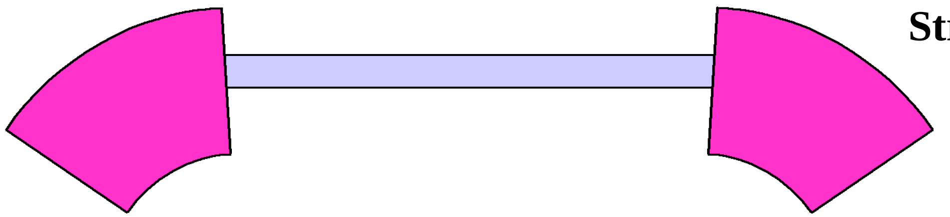
Bend-magnet radiation pattern





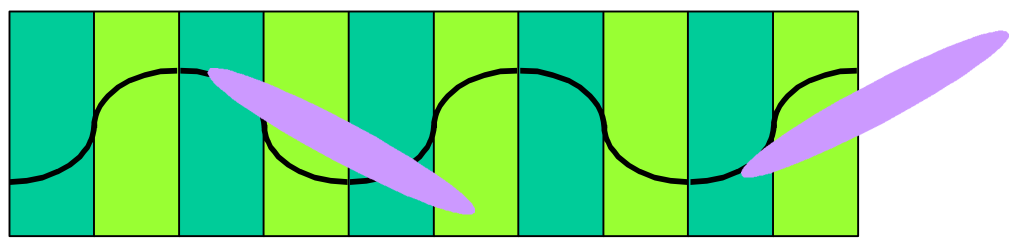
Angular distributions of horizontal and vertical polarizations of Bending Magnet radiation.

Types of synchrotron sources: Insertion devices



Straight section: typically several meters

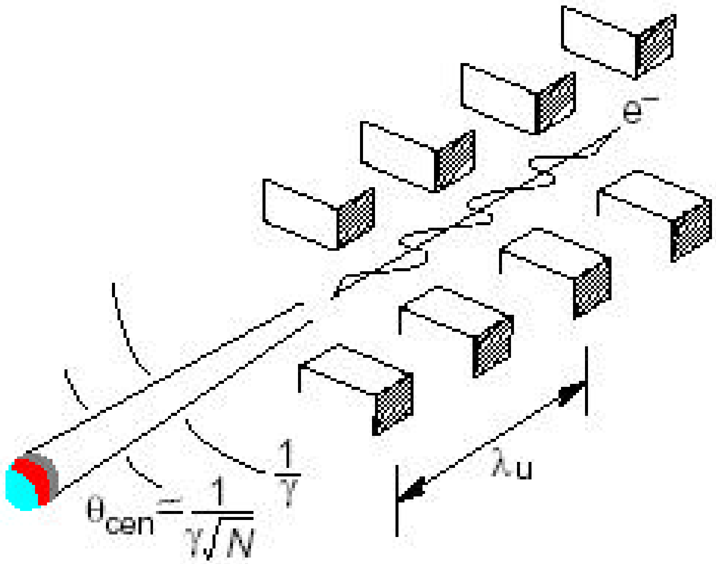
Periodic Magnet Array: 1 meter to 10 meters long



Radiation produced at each bend.

WIGGLER: about 10 periods, very strong fields, large deflections. Intensity builds linearly with number of periods N. Broadband radiation similar to a bending magnet.
UNDULATOR: about 100 periods, weak fields, small deflections. Intensity builds quadratically with number of periods N. Harmonic radiation.

Undulator radiation pattern

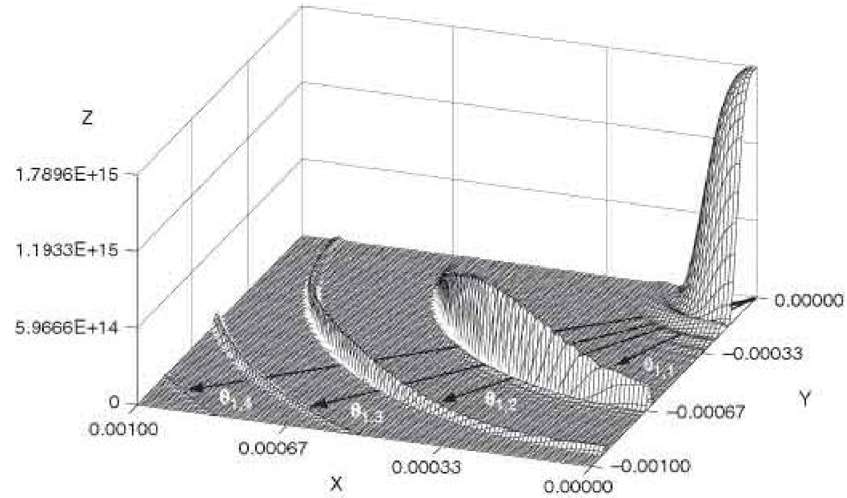


$$\lambda_x = \frac{\lambda_u}{2\gamma^2}\left(1 + \frac{K^2}{2} + \gamma^2\theta^2\right)$$

In the central radiation cone:

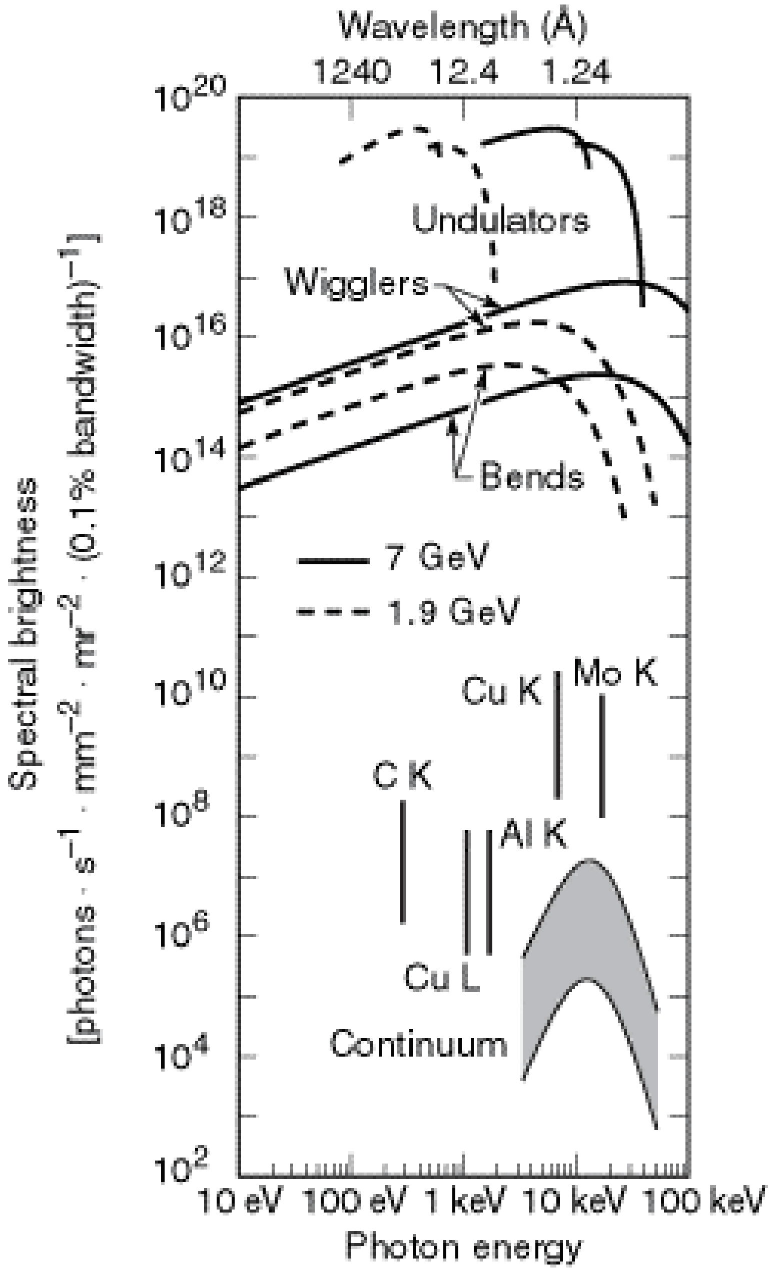
$$\frac{\Delta\omega}{\omega} = \frac{1}{N}$$

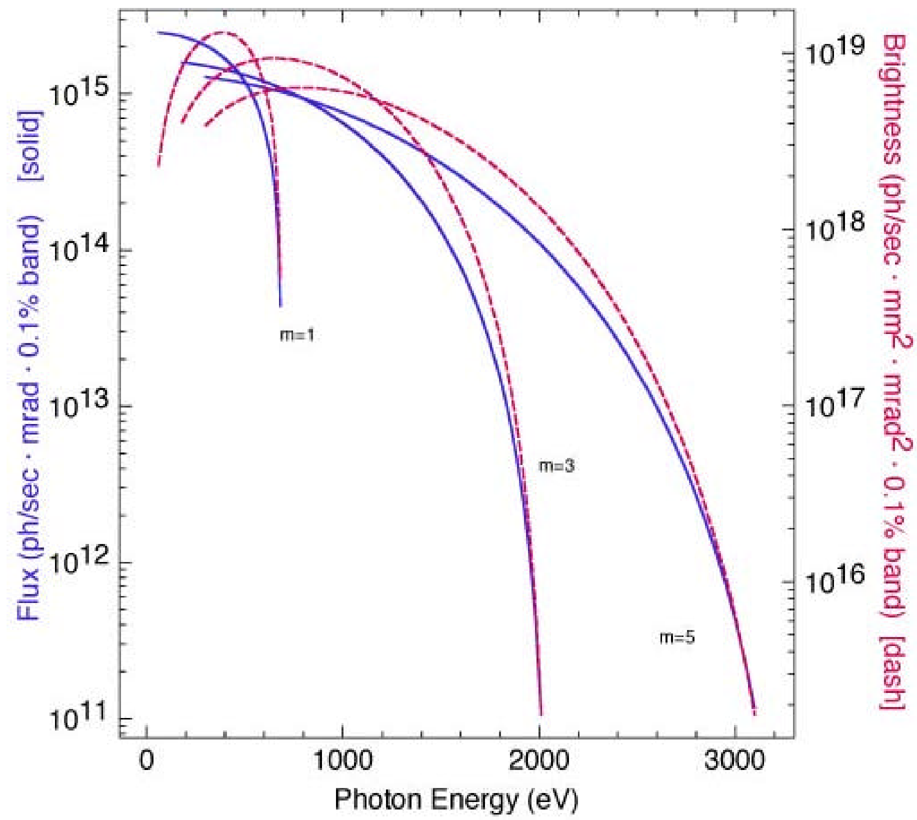
$$\theta_{cen} = \frac{1}{\gamma\sqrt{N}}$$



Angular distribution of Undulator radiation.

Intensity of synchrotron radiation from bending magnets and undulators





Flux and brightness curves for U5 undulator.

Characteristics of synchrotron radiation

- Broadband radiation from infrared to x-ray wavelengths—tunable source with a monochromator
- High average intensity compared to all other sources
- Pulsed: about 1ns pulses at 100MHz repetition rates
- Polarized: highly linearly polarized in plane of storage ring. Elliptical or circular polarization available off-axis or with special insertion devices.
- Collimated to $1/\gamma$ in vertical direction for all types of sources
- Collimated to $1/\gamma$ in horizontal direction for undulator sources

An undulator beamline ALS 7.0