Title
PARTIALLY COHERENT X-RAYS FROM MODERN STORAGE RINGS

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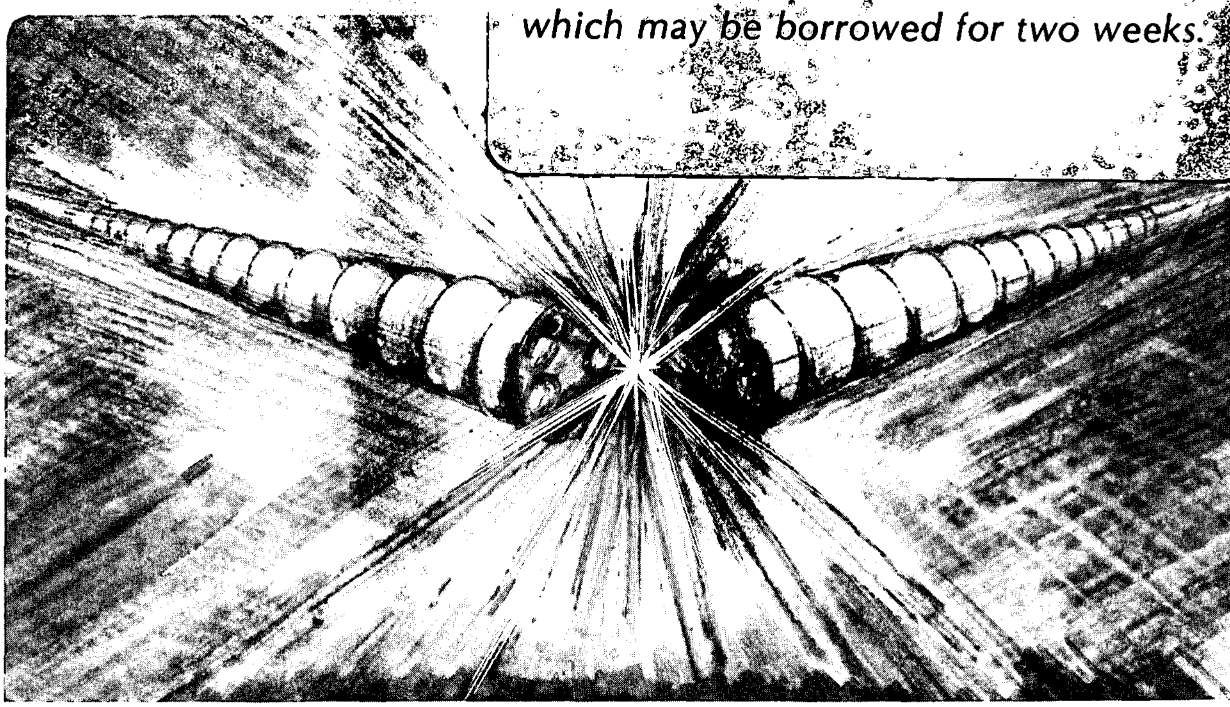

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Partially Coherent X-rays From Modern Storage Rings

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The soft x-ray and vacuum ultraviolet spectral regions (collectively the XUV), extending from photon energies of several electron volts (eV) to several thousand electron volts (KeV), are rich in atomic and molecular structure. The regions include primary resonances of carbon, oxygen and nitrogen, which are important to fields as diverse as biology and microelectronics, as well as myriad molecular resonances. Although previously of limited access to all but a few specialists, the XUV region is now experiencing a renaissance which will open it to a broad class of life, physical and industrial scientists.

Recent review articles[1] describe significant progress in the development of x-ray optical techniques, such as focusing lenses, interference coatings, normal incidence mirrors, picosecond detectors, thin window materials, and so forth. In addition, there is great progress being made in the development of coherent radiation sources[2], which will permit the extension of phase sensitive techniques to this interesting spectral region. These new sources will provide new capabilities for achieving high photon flux levels with narrow spectral widths, picosecond time structure, polarization control, and the ability to point and focus to small sample volumes.

The ideal source of soft x-rays is one of full coherence, and high peak or average power as dictated by applications. Full coherence implies a linewidth limited only by temporal pulse duration, and a perfect phase front (as from a "diffraction limited" source). Several routes to the development of such ideal soft x-ray sources are now being actively pursued. These include atomic lasers, free electron lasers (FELs), and storage ring (synchrotron) undulators. For short wavelength (XUV) applications, FELs and undulators are very closely related, each being dependent on the development of well controlled (low "emittance") electron storage rings, with energies of order 0.5 to 1.5 GeV beam energy, and many period magnetic structures, referred to as undulators. *The major thrust of this article is that undulators provide the only sure route to coherent soft x-rays in the near term, that they are tuneable throughout the region of interest, and that they will serve a multitude of users, in disparate fields of science and technology, albeit at a large central research facility.*

Figure 1 illustrates interesting atomic and molecular transitions that might be utilized to pursue a variety of scientific ends in the pure and applied sciences. Shown in the upper left is the extent to which coherent radiation sources (klystrons, lasers, etc.) are available. Note that they do not extend significantly beyond 1,000Å. Incoherent x-ray sources, particularly broad-band synchrotron radiation facilities, are shown in the lower right. The large block in the overlap region shows the extent to which partially coherent undulators could be utilized to bridge this gap.

Figure 2 illustrates the production of coherent undulator radiation by a very fine, pencil like beam of relativistic electrons traversing a periodic permanent magnet structure. The radiation wavelength is relativistically contracted from centimeter magnetic period lengths to x-ray wavelengths, and appears in a very narrow radiation cone of angular width typically 100 microradians. As observed in the forward direction, undulator radiation is

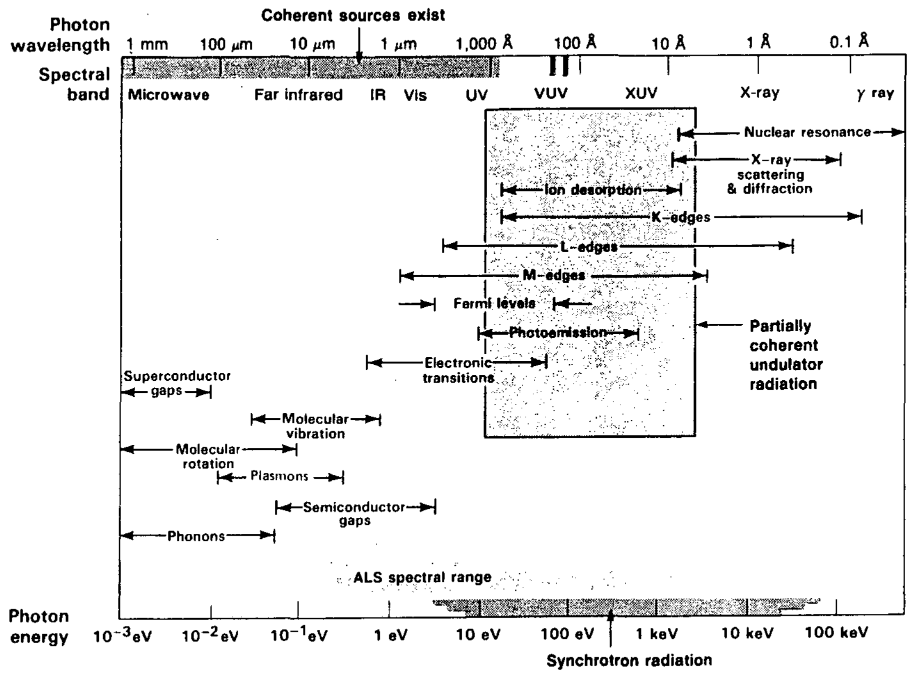


Figure 1. Coherent sources presently extend to about 1,000Å. Incoherent synchrotron radiation sources presently cover the x-ray region. Undulator radiation, at the next generation storage rings, will provide a much needed source of partially coherent radiation in the important soft x-ray and VUV spectral regions.

largely coherent in nature - appearing to come from a near diffraction limited source (small area • solid angle product), and having a narrow spectral width, or order $\lambda/\Delta\lambda \simeq N$. Figure 3 shows the sharp spectral features of a proposed undulator, as well as the spatial radiation pattern ten meters from the source.

Figure 4 shows a comparison of undulator and laser techniques in terms of average coherent power, that is the power radiated with full spatial coherence, and a longitudinal (temporal) coherence of 1 μm (micron) or longer. Note that only undulators are able to provide coherent radiation in the important soft x-ray region. Atomic and molecular lasers, as well as

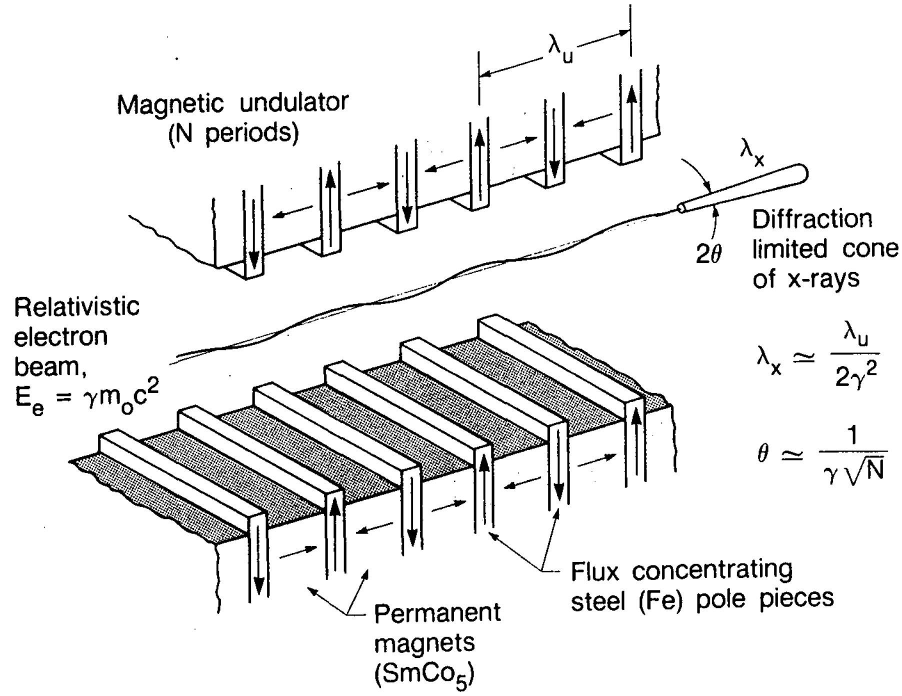


Figure 2 Pencil like beams of relativistic electrons produce spatially coherent x-rays, of relatively narrow spectral width, $\lambda/\Delta\lambda \simeq N$, when traversing a periodic magnetic undulator.

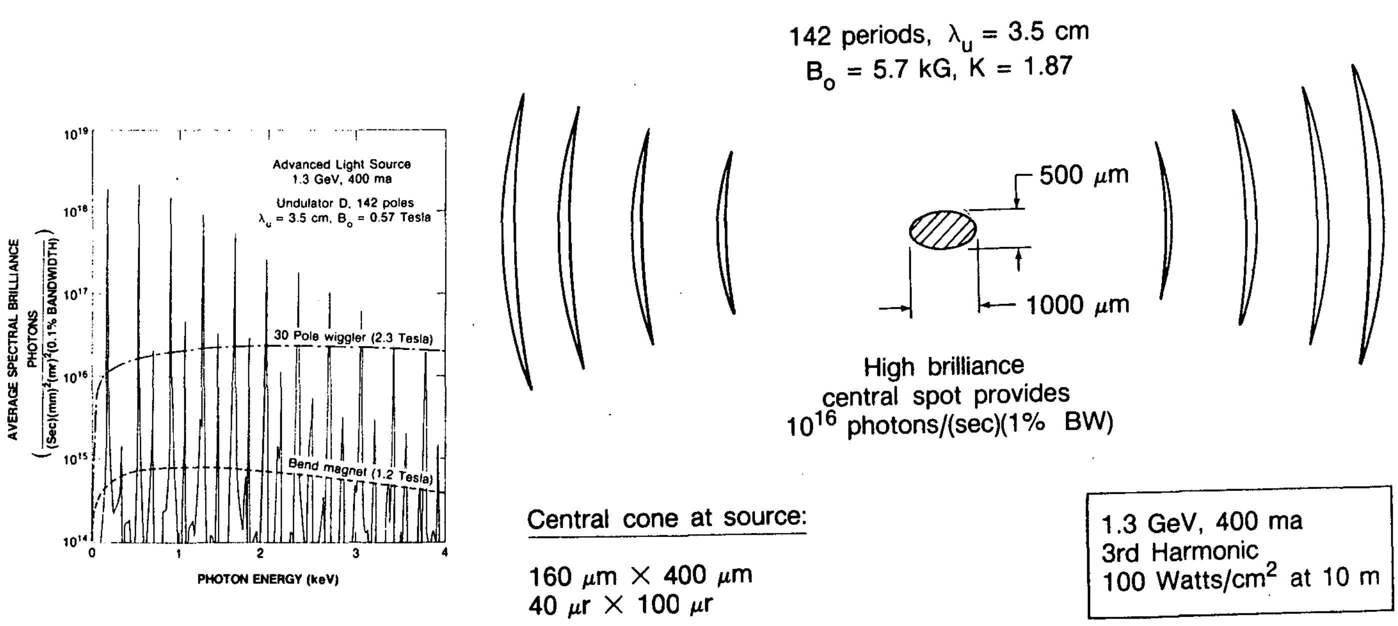
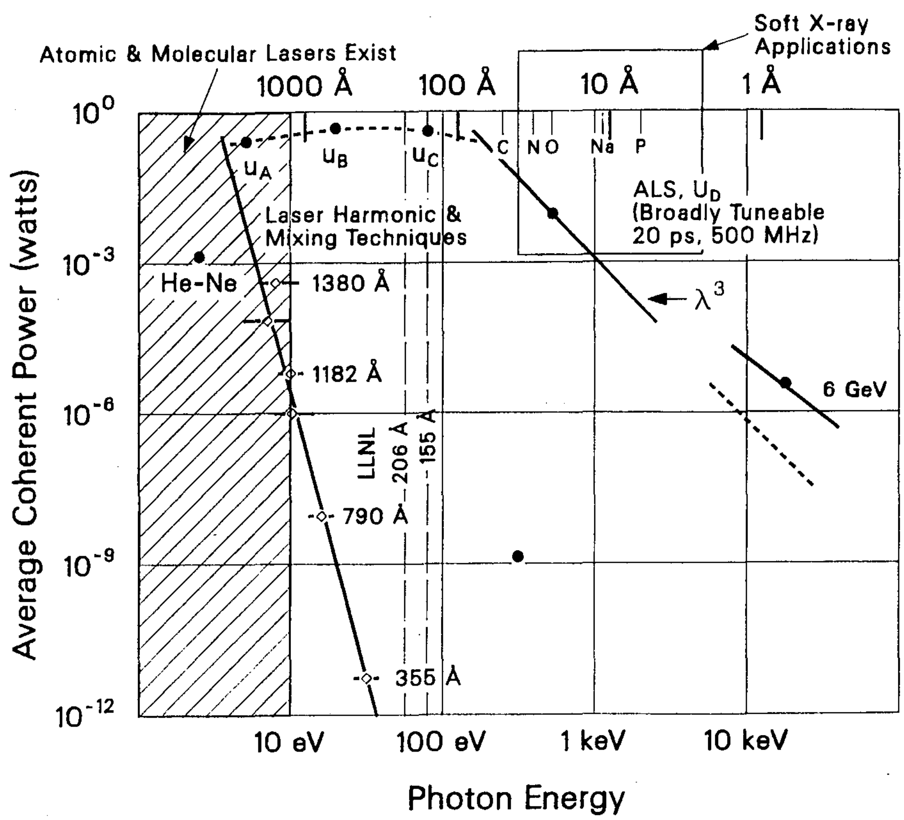


Figure 3 Spatial and temporal radiation calculated for a soft x-ray undulator on the proposed Advanced Light Source at Berkeley.

laser harmonic and mixing techniques, are primarily limited to wavelengths of order 1,000Å. Exciting new results at Lawrence Livermore[3] have now demonstrated lasing techniques to the 200Å region, and we anticipate that these will be extended somewhat below 100Å. These devices will likely reach higher peak power at some point, provide relatively narrow spectral width ($\lambda/\Delta\lambda \sim 10^4$), but will not necessarily possess full spatial coherence, and so are also partially coherent in nature. Other laser techniques[4], of



*Full spatial coherence; longitudinal coherence ≧ 1μm

Figure 4 Partially coherent undulator radiation will be available at wavelengths throughout the VUV and soft x-ray spectral regions at the next generation storage ring facility. With feedback mirrors, or very long undulators, these facilities will eventually provide the first XUV free electron lasers. Atomic and molecular lasers, as well as laser harmonics and mixing techniques, are shown for comparison.

significantly smaller scale, are likely to appear in the several 100Å region over the coming years.

In summary, we see an important role for undulators at next generation storage rings in the coming years. Undulators will provide partially coherent x-rays, at wavelengths to 10Å and beyond. Undulators are tuneable, will be available to a broad array of scientific groups, and importantly, will provide radiation of full spatial coherence, full polarization control, and picosecond time structure.

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