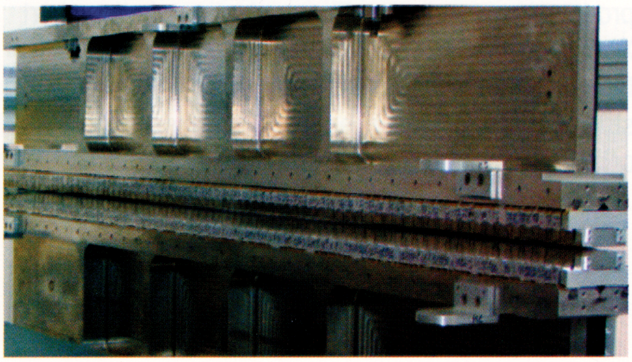
The SPARC free electron Laser Project

SYNCHROTRON LIGHT

A charged particle moving on a curvilinear trajectory spontaneously emits electromagnetic radiation, also known as "Synchrotron Light". The first direct observation of this phenomenon has been done in 1947 by observing the intense light outgoing from a window installed in a small circular particle accelerator, a Synchrotron precisely. For a long time it has been considered a disruptive effect on the dynamics of accelerated particles due to the fact that the particles lose part of their energy in the form of radiated energy. A more careful study of the phenomenon revealed that the Synchrotron Light was the superposition of a wide spectrum of radiation wavelengths, ranging from far-infrared to X-ray, with possible useful and interesting applications. It could have been used in fact as a powerful source of radiation for investigations on the microscopic nature of materials, cells, proteins and to obtain high resolution images of biological tissues.

THE FREE ELECTRON LASER

The Free Electron Laser, often called FEL, is a source of Synchrotron Light that can produce monochromatic electromagnetic radiation even at a wavelength shorter than one millionth of a millimeter (X rays).



This device consists essentially of a long magnet, called "undulator", see Fig. 1, characterized by a sinusoidal magnetic field produced by a series of small magnets with alternating polarity. In the undulator is injected a high density electron beam produced by a linear accelerator (Linac). Within this magnetic structure, the electrons emit radiation which wavelength, called resonant wavelength, is proportional to the ratio between the undulator period and the square of the electron energy. The behavior of the electron beam during its propagation inside the undulator can be considered in 3 phases.

In a first phase, known as **lethargy**, the interaction between the electron beam and the radiation emitted by the beam itself produces a spatial redistribution of electrons into small packets, spaced exactly one radiation wavelength, see Fig. 2.

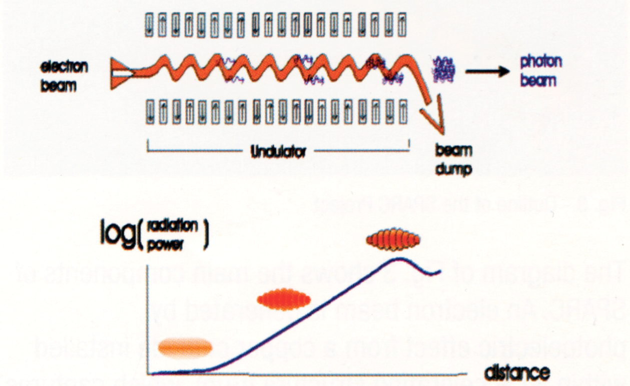


Fig. 2 – The motion of the electrons within the undulators and the corresponding growth of emitted radiation power

In this way, billions of electrons self-organize to radiate coherently resulting in an **exponential growth** of the emitted power. The process stops when the electrons have converted a significant fraction (5%) of their initial kinetic energy into electromagnetic energy and they do not meet anymore "the resonance condition". This last phase is called **saturation**.
Since the emitted radiation wavelength depends on the electron energy one can tune the radiation wavelength, an impossible feature for conventional atomic lasers, by changing the energy of the beam

injected in the undulator. FEL devices will increase the peak power (photon flux) by several orders of magnitude compared to the most advanced synchrotron light sources, with significant benefits for research and industrial technology. It will be possible to use innovative techniques, based on X-ray imaging, in materials science (nanotechnology), in biology and in medicine. FEL will also open new perspectives in the X-ray microscopy and new methodologies in the field of protein crystallography.

THE SPARC PROJECT

Born from a collaboration between INFN, ENEA and CNR, the first Italian FEL started its operation in January 2009 in Frascati. At present SPARC can generate monochromatic radiation at 500 nm (in the region of the electromagnetic spectrum corresponding to green). A beam energy upgrade able to produce VUV radiation is also foreseen in the near future.

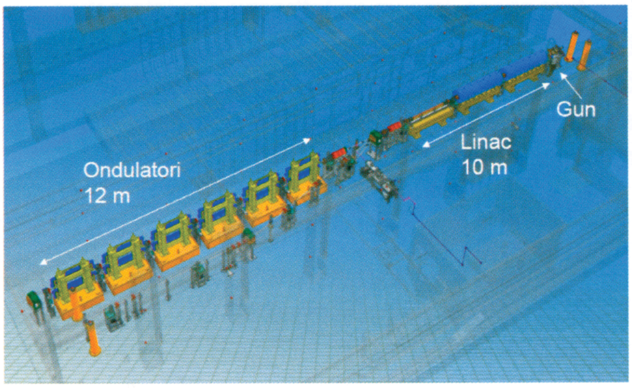


Fig. 3 - Outline of the SPARC Project

The diagram of Fig. 3 shows the main components of SPARC. An electron beam is generated by photoelectric effect from a copper cathode installed within an accelerating structure (Gun), which captures the beam and accelerates up to an energy of 5 MeV. The beam is further accelerated up to an energy of 150 MeV by three accelerating structures (Linac) and injected into the undulator, composed by six 2 meters long modules. To change the beam energy and thus the "color" of the emitted radiation it is enough to change the accelerating field intensity in the Linac structures. Two recent images of SPARC are shown in Fig. 4 and 5.

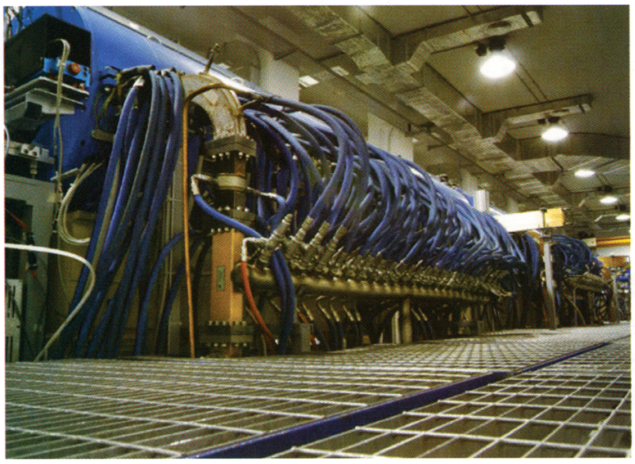


Fig. 4 - View of the SPARC Linac

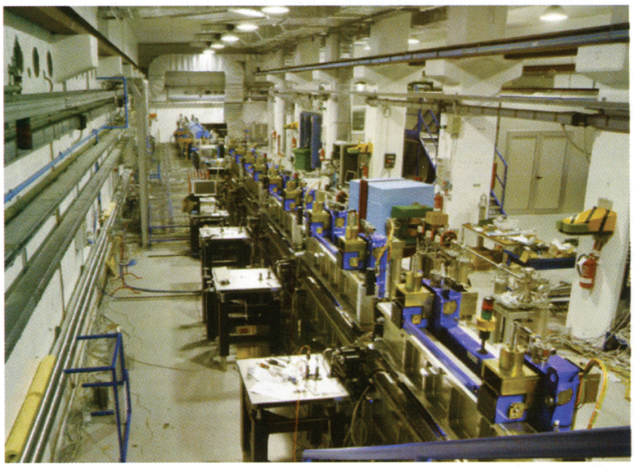


Fig. 5 - View of the SPARC undulators

SPARC is a Research and Development (R&D) facility in which new electron beam generation schemes and innovative solutions to improve the quality and the time duration of the emitted radiation will be studied, in view of possible developments in the Roman area of a higher energy machine of (1 - 2 GeV) able to produce X-ray radiation. The production of ultra-short X-ray radiation pulses, lasting less than 100 femtosecond, could open new perspectives for the study of ultra fast bio-chemical reactions, such as the one involving DNA modifications.