M.Sc Physics------Core Course-X-------Advanced Physics

Unit -1 Astro Physics and Radio Astronomy

Star:

A star is a massive ball of plasma that emits light throughout the universe. There is only one star in our solar system, there are billions upon billions of stars throughout our galaxy and exponentially more in the billions of galaxies in the universe.

A star can be defined by five basic characteristics:

Brightness, color, surface temperature, size and mass.

Brightness:

Two characteristics define brightness: Luminosity and magnitude.

* Luminosity is the amount of light that a star radiates. The size of the star and its surface temperature determine its luminosity.
* Apparent magnitude of a star is its perceived brightness, factoring in size and distance
* Absolute magnitude is its true brightness irrespective of its distance from earth.

Color:

A star's color depends on its surface temperature. Cooler stars tend to be redder in color, while hotter stars have a bluer appearance. Stars in the mid ranges are white or yellow, such as our sun. Stars can also blend colors, such as red-orange stars or blue-white stars.

## Surface Temperature:

Astronomers measure a star's temperature on the Kelvin scale. Zero degrees on the Kelvin scale is theoretically absolute and is equal to -273.15 degrees Celsius. The coolest, reddest stars are approximately 2,500 K, while the hottest stars can reach 50,000 K. Our sun is about 5,500 K.

## Size:

Astronomers measure the size of a given star in terms of our own sun's radius. Thus, a star that measure 1 solar radii would be the same size as our sun. The star Rigel, which is much larger than our sun, measures 78 solar radii. A star's size, along with its surface temperature, will determine its luminosity.

## Mass

A star's mass is also measured in terms of our own sun, with 1 equal to the size of our sun. For instance, Rigel, which is much larger than our sun, has a mass of 3.5 solar masses. Two stars of a similar size may not necessarily have the same mass, as stars can vary greatly in density.

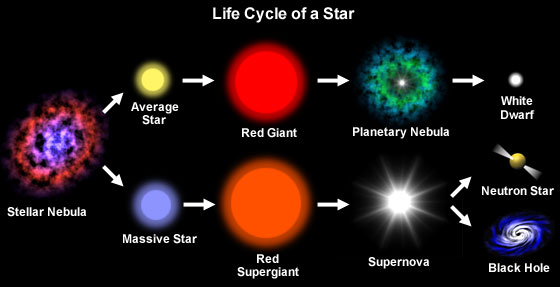
Properties of stars:

* Distance: This is determined from trigonometric and spectroscopic parallaxes. Determining distances is crucial to understanding stars because we can use distances to figure out
  + the scale of things in the Galaxy and
  + how much energy stars produce and radiate away -   
    by using the inverse square law for light dimming along with apparent brightnesses.
* Luminosity: This is the amount of energy generated in the star and released as electromagnetic radiation.
* Brightness: This is not a fundamental property but a combination of the luminosity and distance to a star
* Raduis:"Size" of the star - calculated from Stephan's Law.
* Chemical composition: This is determined from absorption line spectra; it is tied up in a semi-complicated way with temperature.

Life Cycle of a Star:

Life Cycles of Stars. A star's life cycle is determined by its mass. ... A star's mass is determined by the amount of matter that is available in its nebula, the giant cloud of gas and dust from which it was born. Over time, the hydrogen gas in the nebula is pulled together by gravity and it begins to spin.

Stars are [formed](https://www.schoolsobservatory.org/learn/astro/stars/formation) in clouds of gas and dust, known as nebulae. [Nuclear reactions](https://www.schoolsobservatory.org/learn/science/nuclear/fusion) at the centre (or core) of stars provides enough energy to make them shine brightly for many years. The exact lifetime of a [star](https://www.schoolsobservatory.org/learn/astro/stars) depends very much on its [size](https://www.schoolsobservatory.org/learn/astro/stars/class/starsize). Very large, massive stars burn their fuel much faster than smaller stars and may only last a few hundred thousand years. Smaller stars, however, will last for several billion years, because they burn their fuel much more slowly.



The hydrogen fuel that powers the nuclear reactions within stars will begin to run out, and they will enter the final phases of their lifetime. Over time, they will expand, cool and change colour to become [red giants](https://www.schoolsobservatory.org/learn/astro/stars/cycle/redgiant). The path they follow beyond that depends on the [mass](https://www.schoolsobservatory.org/learn/science/mass) of the star.

Small stars, like the [Sun](https://www.schoolsobservatory.org/learn/astro/solsys/sun), undergo a relatively peaceful and beautiful death that sees them pass through a [planetary nebula](https://www.schoolsobservatory.org/learn/astro/stars/cycle/planetary) phase to become a [white dwarf](https://www.schoolsobservatory.org/learn/astro/stars/cycle/whitedwarf), which eventually cools down over time and stops glowing to become a so-called "black dwarf".

Massive stars, on the other hand, will experience a most energetic and violent end, which will see their remains scattered about the cosmos in a enormous explosion, called a [supernova](https://www.schoolsobservatory.org/learn/astro/stars/cycle/supernova). Once the dust clears, the only thing remaining will be a very dense star known as a [neutron star](https://www.schoolsobservatory.org/learn/astro/stars/cycle/neutron), these can often be rapidly spinning and are known as [pulsars](https://www.schoolsobservatory.org/learn/astro/stars/cycle/pulsar). If the star which explodes is especially large, it can even form a [black hole](https://www.schoolsobservatory.org/learn/astro/stars/cycle/blackholes).

End products of stellar revolution:

Stellar evolution is the process by which a [star](https://en.wikipedia.org/wiki/Star) changes over the course of time. Depending on the mass of the star, its lifetime can range from a few million years for the most massive to trillions of years for the least massive, which is considerably longer than the [age of the universe](https://en.wikipedia.org/wiki/Age_of_the_universe). All stars are formed from [collapsing](https://en.wikipedia.org/wiki/Gravitational_collapse) clouds of gas and dust, often called [nebulae](https://en.wikipedia.org/wiki/Nebula) or [molecular clouds](https://en.wikipedia.org/wiki/Molecular_cloud). Over the course of millions of years, these [protostar](https://en.wikipedia.org/wiki/Protostar) settle down into a state of equilibrium, becoming what is known as a [main-sequence](https://en.wikipedia.org/wiki/Main_sequence) star.

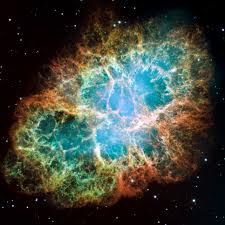
[Nuclear fusion](https://en.wikipedia.org/wiki/Nuclear_fusion) powers a star for most of its existence. Initially the energy is generated by the fusion of [hydrogen atoms](https://en.wikipedia.org/wiki/Hydrogen_atoms) at the [core](https://en.wikipedia.org/wiki/Stellar_core) of the main-sequence star. Later, as the preponderance of atoms at the core becomes [helium](https://en.wikipedia.org/wiki/Helium), stars like the [Sun](https://en.wikipedia.org/wiki/Sun) begin to fuse hydrogen along a spherical shell surrounding the core. This process causes the star to gradually grow in size, passing through the [subgiant](https://en.wikipedia.org/wiki/Subgiant) stage until it reaches the [red giant](https://en.wikipedia.org/wiki/Red_giant) phase.

Stars with at least half the mass of the Sun can also begin to generate energy through the fusion of helium at their core, whereas more-massive stars can fuse heavier elements along a series of concentric shells. Once a star like the Sun has exhausted its nuclear fuel, its core collapses into a dense [white dwarf](https://en.wikipedia.org/wiki/White_dwarf) and the outer layers are expelled as a [planetary nebula](https://en.wikipedia.org/wiki/Planetary_nebula). Stars with around ten or more times the mass of the Sun can explode in a [supernova](https://en.wikipedia.org/wiki/Supernova) as their inert iron cores collapse into an extremely dense [neutron star](https://en.wikipedia.org/wiki/Neutron_star) or [black hole](https://en.wikipedia.org/wiki/Black_hole).

Stellar evolution is not studied by observing the life of a single star, as most stellar changes occur too slowly to be detected, even over many centuries. Instead, [astrophysicists](https://en.wikipedia.org/wiki/Astrophysics) come to understand how stars evolve by observing numerous stars at various points in their lifetime, and by simulating [stellar structure](https://en.wikipedia.org/wiki/Stellar_structure) using [computer models](https://en.wikipedia.org/wiki/Computer_model).

Stellar Nebulla:

Mutual gravitational attraction causes matter to clump together, forming regions of greater and greater density. From this, stars may form in the center of the collapsing material, who's ultraviolet ionizing radiation causes the surrounding gas to become visible at optical wavelengths.



Average Star:

An average star, or intermediate-mass star, is a star with an initial mass of 0.5 to 8 times that of Earth's sun. It spends most of its time on the main sequence as an orange, yellow, or blue-white dwarf star.



Red Giant:

In approximately 5 billion years, the sun will begin the helium-burning process, turning into a red giant star. When it expands, its outer layers will consume Mercury and Venus, and reach Earth. ... When stars morph into red giants, they change the habitable zones of their system.



Planetary Nebulla

A ring-shaped nebula formed by an expanding shell of gas round an ageing star. A planetary nebula is created when a star blows off its outer layers after it has run out of fuel to burn. These outer layers of gas expand into space, forming a nebula which is often the shape of a ring or bubble.



White Dwarf:

A white dwarf, also called a degenerate dwarf, is a stellar core remnant composed mostly of electron-degenerate matter. A white dwarf is very dense: its mass is comparable to that of the Sun, while its volume is comparable to that of Earth.



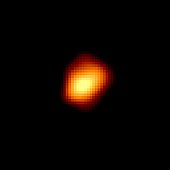
Massive Star:

A massive star is a star that is larger than eight solar masses during its regular main sequence lifetime. Massive stars are born, just like average stars, out of clouds of dust called nebulae.



Red Super giant:

A red supergiant is an aging giant star that has consumed its core's supply of hydrogen fuel. Helium has accumulated in the core, and hydrogen is now undergoing nuclear fusion in the outer shells. These shells then expand, and the now cooler star takes on a redcolor. They are the largest known stars.



Neutron star

A celestial object of very small radius (typically 30 km) and very high density, composed predominantly of closely packed neutrons. Neutron stars are thought to form by the gravitational collapse of the remnant of a massive star after a supernova explosion, provided that the star is insufficiently massive to produce a black hole.



Black Hole:

A black hole is a region of spacetime exhibiting gravitational acceleration so strong that nothing—no particles or even electromagnetic radiation such as light—can escape from it. The theory of general relativity predicts that a sufficiently compact mass can deform spacetime to form a black hole.



Structure of Milky Way:

This **structure** can be viewed as consisting of six separate parts: (1) a nucleus, (2) a central bulge, (3) a disk (both a thin and a thick disk), (4) spiral arms, (5) a spherical component, and (6) a massive halo. Some of these components blend into each other. Three views of the **Milky Way** Galaxy

The size and structure of the Milky Way galaxy

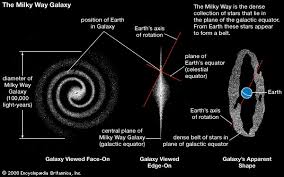
Structure and Composition. The galaxy we live in, called the Milky Way Galaxy, is a barred spiral galaxy composed of at least 100 billion stars. It is approximately 100,000 light years across and about 1000 light years thick. It has a central bulge that is about 10,000 light years in diameter.

The three main parts of the Milky Way:Visible Components

A spiral galaxy like the Milky Way has three basic components to its visible matter: the disk (containing the spiral **arms**), the halo, and the nucleus or central bulge

The features of the Milky WayIt's Warped: ...

* It Has a Halo, but You Can't Directly See It: ...
* It has Over 200 Billion Stars: ...
* It's Really Dusty and Gassy: ...
* It was Made From Other Galaxies: ...
* Every Picture You've Seen of the Milky Way Isn't It: ...
* There is a Black Hole at the Center: ...
* It's Almost as Old as the Universe Itself:

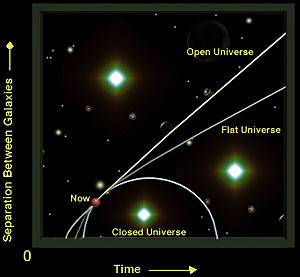


Expanding universe:

The **expansion of the universe** is the increase in [distance](https://en.wikipedia.org/wiki/Proper_length) between any two given [gravitationally unbound](https://en.wikipedia.org/wiki/Gravitationally_bound) parts of the [observable universe](https://en.wikipedia.org/wiki/Observable_universe) with [time](https://en.wikipedia.org/wiki/Chronology_of_the_universe).[[1]](https://en.wikipedia.org/wiki/Expansion_of_the_universe#cite_note-NYT-20170220-1) It is an [intrinsic](https://en.wikipedia.org/wiki/Intrinsic_and_extrinsic_properties_(philosophy))expansion whereby *the scale of space itself changes*. The universe does not expand "into" anything and does not require space to exist "outside" it. Technically, neither space nor objects in space move. Instead it is the [metric](https://en.wikipedia.org/wiki/Metric_tensor_(general_relativity)) governing the size and geometry of [space time](https://en.wikipedia.org/wiki/Spacetime) itself that changes in scale. Although light and objects within space time cannot travel faster than the [speed of light](https://en.wikipedia.org/wiki/Speed_of_light), this limitation does not restrict the metric itself. To an observer it appears that space is expanding and all but [the nearest galaxies](https://en.wikipedia.org/wiki/Local_Group) are receding into the distance.

During the [inflationary epoch](https://en.wikipedia.org/wiki/Inflationary_epoch) about 10−32 of a second after the [Big Bang](https://en.wikipedia.org/wiki/Big_Bang), the universe suddenly expanded, and its volume increased by a factor of at least 1078 (an expansion of distance by a factor of at least 1026 in each of the three dimensions), equivalent to expanding an object 1 [nanometer](https://en.wikipedia.org/wiki/Nanometer) (10−9[m](https://en.wikipedia.org/wiki/Meter), about half the width of a [molecule](https://en.wikipedia.org/wiki/Molecule) of [DNA](https://en.wikipedia.org/wiki/DNA)) in length to one approximately 10.6 [light years](https://en.wikipedia.org/wiki/Light_years) (about 1017[m](https://en.wikipedia.org/wiki/Meter) or 62 trillion miles) long. A much slower and gradual expansion of space continued after this, until at around 9.8 billion years after the Big Bang (4 billion years ago) it began to gradually [expand more quickly](https://en.wikipedia.org/wiki/Accelerating_expansion_of_the_universe), and is still doing so.

The metric expansion of space is of a kind completely different from the [expansions](https://en.wikipedia.org/wiki/Thermal_expansion) and [explosions](https://en.wikipedia.org/wiki/Explosion) seen in daily life. It also seems to be a property of the [universe as a whole](https://en.wikipedia.org/wiki/Mathematics_of_general_relativity#Local_versus_global_structure) rather than a phenomenon that applies just to one part of the universe or can be observed from "outside" of it.



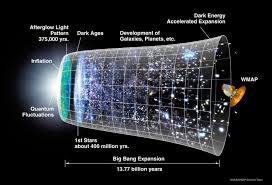
Future prospects:

Observations suggest that the **expansion** of the **universe** will continue forever. If so, then a popular theory is that the **universe** will cool as it **expands**, eventually becoming too cold to sustain life. For this reason, this **future** scenario once popularly called "Heat Death" is now known as the Big Chill or Big Freeze.

Expansion of the universe

The expansion of the universe is the increase in distance between any two given gravitationally unbound parts of the observable universe with time. It is an intrinsic expansion whereby the scale of space itself changes.

As long as the amount of stuff doesn't go over a critical threshold, the **universe will** continue to **expand** forever, and eventually suffer heat death, freezing out. But if there's too much stuff, the **expansion** of the **universe will** slow down and **stop**. Then the **universe will** begin to contract.



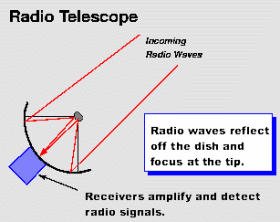
Radio Astronomy:

**Radio Telescopes**

Just as optical telescopes, radio telescopes collect visible light, bring it to a focus, amplify it and make it available for analysis by various instruments. Radio telescopes are used to study the naturally occurring radio light from stars, galaxies, black holes, and other astronomical objects. They are also used to transmit and reflect radio light off of planetary bodies in our solar system. These specially-designed telescopes observe the longest wavelengths of light, ranging from 1 millimeter to over 10 meters long.

For comparison, visible light waves are only a few hundred nanometers long, and a nanometer is only 1/10,000th the thickness of a piece of paper. Naturally occurring radio waves are extremely weak by the time they reach us from space. A cell phone signal is a billion billion times more powerful than the cosmic waves our telescopes detect.

**Parts of a Radio Telescope**



Radio telescopes are built in all shapes and sizes based on the kind of radio waves they pick up. Every radio telescope has an antenna on a mount and at least one piece of receiver equipment to detect the signals.

Because radio waves are so long and cosmic radio sources are extremely weak, radio telescopes are the largest telescopes in the world, and only the most sensitive radio receivers are used inside them.

**The Antenna**

The most basic antenna is a metal dipole antenna, often used on cars to pick up the radio waves broadcasters use to carry their audio shows.

The most versatile and powerful type of radio telescope is the parabolic dish antenna. The parabola is a useful mathematical shape that forces incoming radio waves to bounce up to a single point above it, called a focus. Dish antennae bounce many different wavelengths at once, and needs different receivers to tune to different frequency channels.

**Feed Supports**

Hanging a feed horn and receiver at the focus above the dish, or install a mirror to redirect the focused waves down into the center of the dish where multiple receivers are arranged. If we place receivers at the focus, above the dish, the detected signal travels by cable along the feed support structure to a point near the ground where it can be recorded and analyzed. These prime focus feeds are limited by the weight and size of the feed horn that will safely fit up there and how tricky it might be to reach them for human maintenance.

**Dish Surface**

If the lengths of the radio waves are very small, such as the millimeter waves collected by ALMA, then the perfection of the telescope’s dish surface is critical. Any warp, bump, or ding in the parabola will scatter these tiny waves away from the focus, will cause loss of information.

Wind and temperature differences can deform the parabola of a big radio telescope’s dish and the pull of gravity affects the heavy antenna as it tilts to different parts of the sky. Therefore, the dishes of ALMA are kept small in order to better control their perfect shapes under these constantly varying conditions.

If the size of the radio wavelength being observed is very long, such as the centimeter waves picked up by the VLA and the VLBA, then the perfection of the dish’s shape is not as critical to keep excellent observations of the radio sky. Those dishes are made rigid and tough and withstand the rigors of moving and working in various conditions.

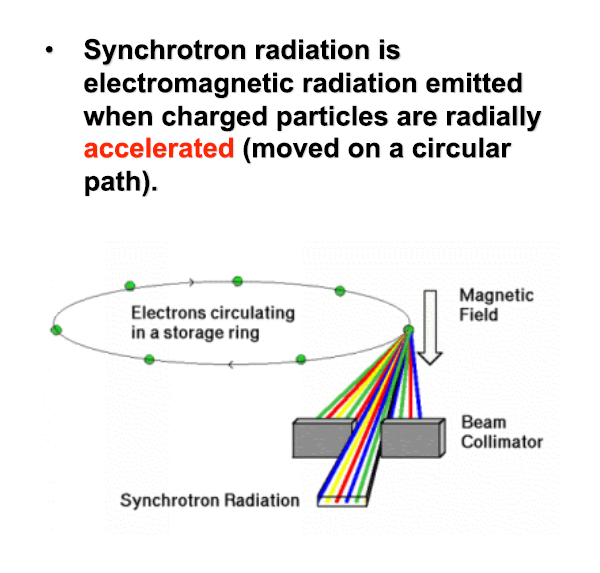
**Telescope Mounts**

The dishes of some radio telescopes spin around a shaft that is aimed at the North Pole Star. These equatorial mounts allow the telescope to follow a position in the sky as the Earth rotates, simply by copying the Earth’s axis of rotation and moving against it. But large equatorially-mounted radio telescopes are difficult to build, because they require millions of pounds of telescope to balance at many awkward angles. The largest ever built is our 140-foot (43-meter) dish telescope in Green Bank.

In most modern radio telescopes, a digital computer drives the telescope on simpler tilt and turn axes . This is how we can fully-steer 17 millions pounds of the GBT all across the sky.

Synchrotron Radiation:

Synchrotron radiation is electromagnetic radiation emitted when charged particle are radially accelerated (moved on a circular path)



Natural synchrotron radiation from charged particles spiral around magnetic-field lines in space is as old as the stars, for example the light we see from the Crab Nebula. Short-wavelength synchrotron radiation generated by relativistic electrons in circular accelerators is only a half-century old.

The first observation, literally since it was visible light that was seen, came at the General Electric Research Laboratory in Schenectady, New York, on April 24, 1947. In the 60 years since, synchrotron radiation has become a premier research tool for the study of matter in all its varied manifestations, as facilities around the world constantly evolved to provide this light in ever more useful forms

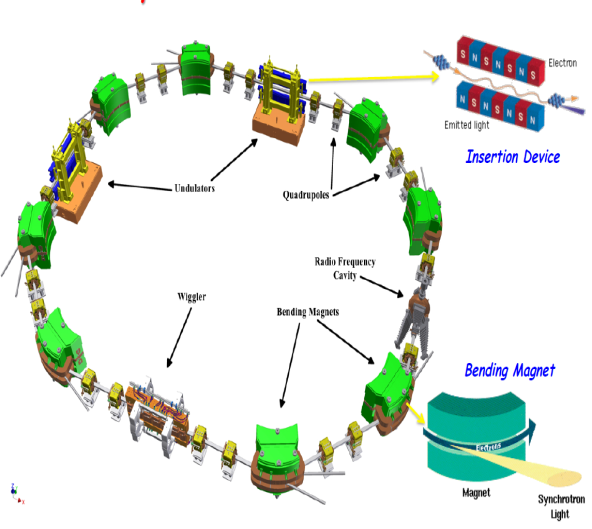
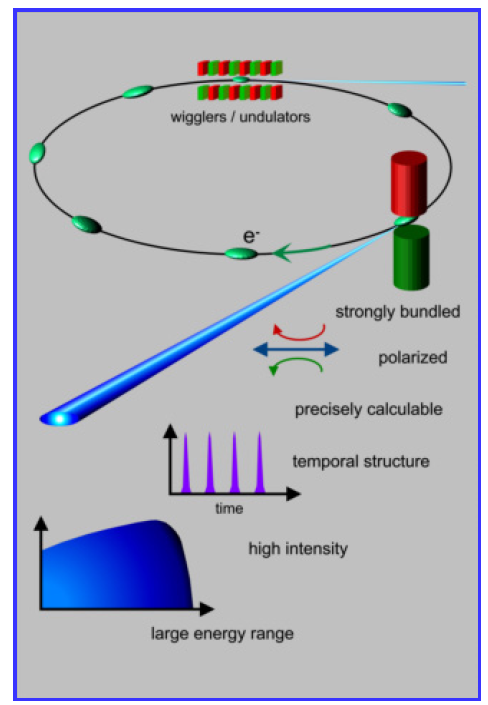
A synchrotron (sometimes called a synchro-cyclotron) is a circular accelerator which has an electromagnetic resonant cavity (or perhaps a few placed at regular intervals around the ring) to accelerate the particles.

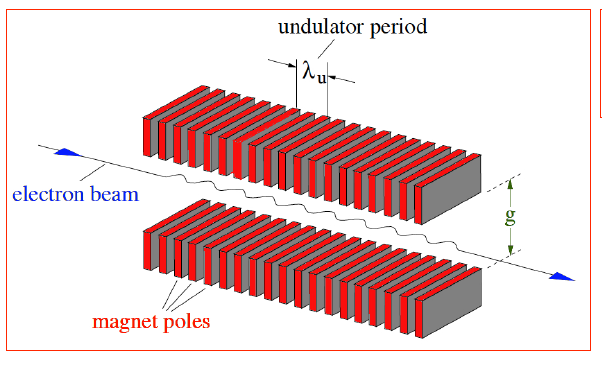
A storage ring is the same thing as a synchrotron, except that it is designed just to keep the particles circulating at a constant energy for as long as possible, not to increase their energy any further. However, the particles must still pass through at least one accelerating cavity each time they circle the ring, just to compensate for the energy they lose to synchrotron radiation.

First generation: parasitic operation

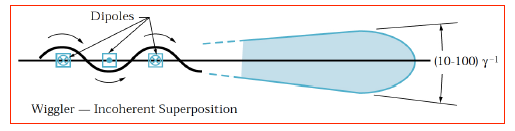
Second generation: dedicated operation

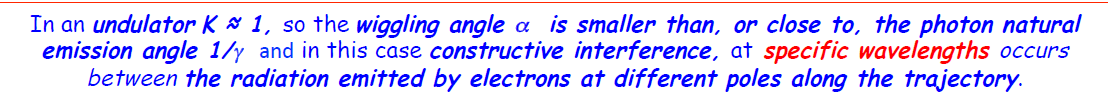
Third generation: undulators and wigglers

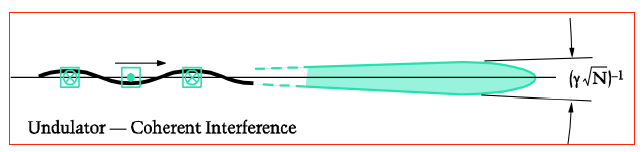
 

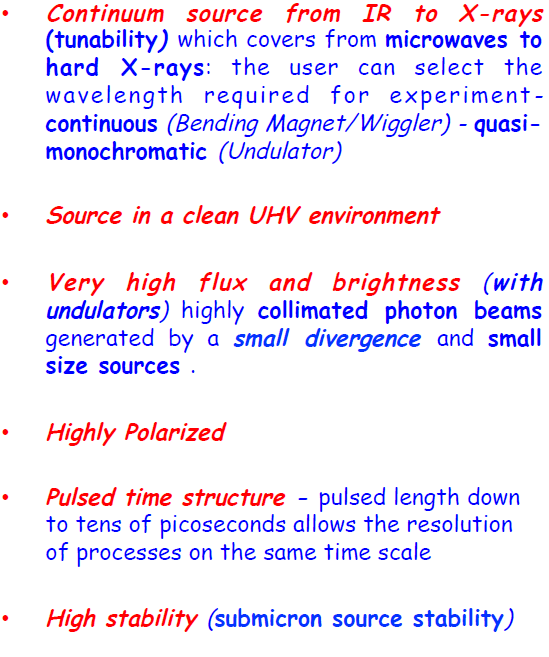


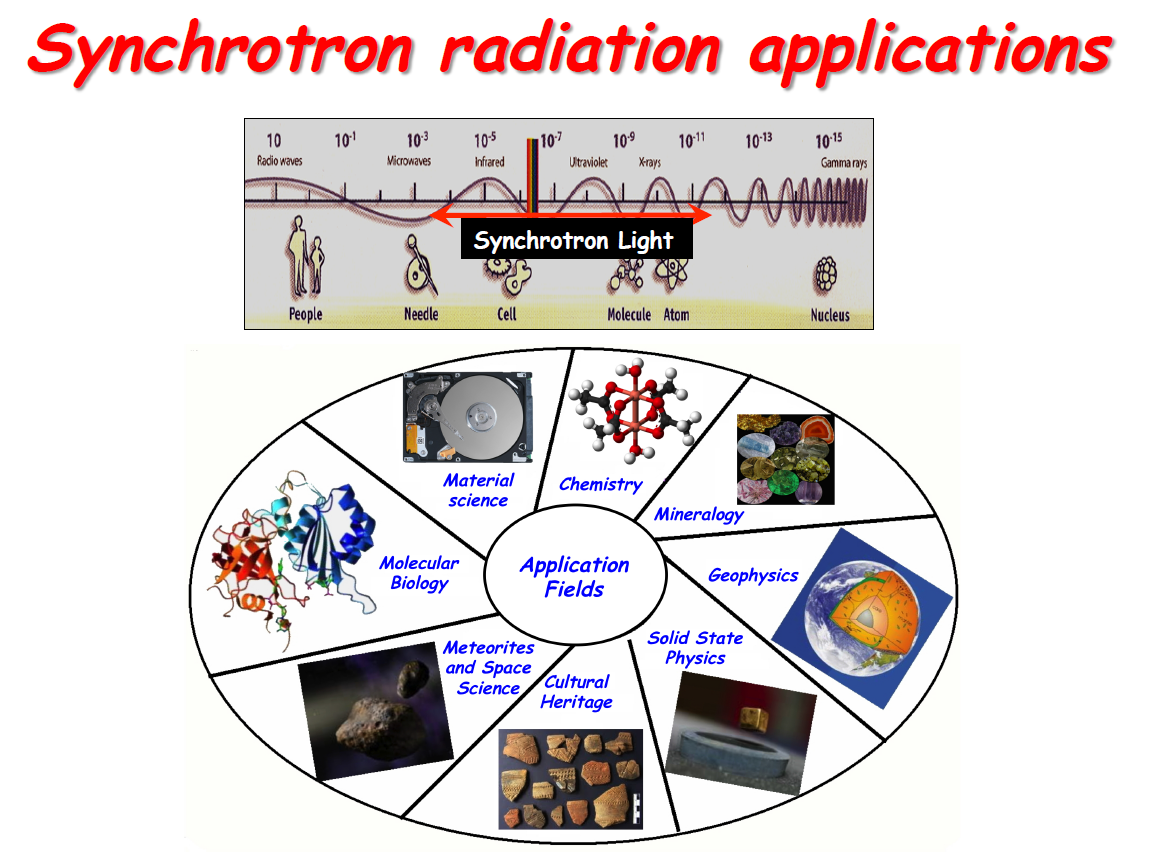
A wiggler is a multi pole magnet PMW made up of a periodic series of magnets. Electrons are forced to follow a sinusoidal trajectory with a smaller local radius of curvature with respect to the one of the dipole-bending magnet, because in a wiggler, a magnetic field higher than in a bending magnet can be used











Hot big bang cosmology:

The broadly accepted theory for the origin and evolution of our universe is the Big Bang model

It states that the universe began as hot, dense point roughly 13.7 billion years ago.

How It All Started

The Big Bang was not an explosion in space.

It was the appearance of space everywhere in the universe.

The observations of the cosmic microwave background, that contains the afterglow of light and radiation left over from the Big Bang.

In 2001, NASA launched the Wilkinson Microwave Anisotropy Probe (WMAP) mission to study the conditions as they existed in the early universe by measuring radiation from the cosmic microwave background.

Determined the age of the universe is about 13.7 billion years old.

## The Universe's First Growth Spurt

When the universe was very young, it underwent an incredible growth spurt. During this burst of expansion, it is known as inflation, hence, the universe grew exponentially and doubled in size at least 90 times.  
  
"The universe was expanding, and as it expanded, it got cooler and less dense.

After inflation, the universe continued to grow, but at a slower rate. As space expanded, the universe cooled and matter formed.

## Too Hot to Shine

Light chemical elements were created within the first three minutes of the universe's formation.

As the universe expanded, temperatures cooled and protons and neutrons collided to make deuterium, which is an isotope of hydrogen. Much of this deuterium combined to make helium.  
  
For the first 380,000 years after the Big Bang, the intense heat from the universe's creation made it too hot for light to shine.

Atoms crashed together with enough force to break up into a dense, opaque plasma of protons, neutrons and electrons that scattered light like fog.

Let there be light

About 380,000 years after the Big Bang, matter cooled enough for electrons to combine with nuclei to form neutral atoms. This phase is known as "recombination,"

The absorption of free electrons caused the universe to become transparent.

The light that was unleashed at this time is detectable today in the form of radiation from the cosmic microwave background.  
  
**Emerging from the Cosmic Dark Ages**

Roughly 400 million years after the Big Bang, the universe began to come out of its dark ages.

This period in the universe's evolution is called the age of re-ionization.  
  
During this time, clumps of gas collapsed enough to form the very first stars and galaxies.

The emitted ultraviolet light from these energetic events cleared out and destroyed most of the surrounding neutral hydrogen gas. The process of re-ionization, plus the clearing of foggy hydrogen gas, caused the universe to become transparent to ultraviolet light for the first time.

## More Stars and More Galaxies

Astronomers comb the universe looking for the most far-flung and oldest galaxies to help them understand the properties of the early universe.

## Birth of Our Solar System

According to current estimates, the sun is one of more than 100 billion stars in our Milky Way galaxy alone, and orbits roughly 25,000 light-years from the galactic core.   
  
Many scientists think the sun and the rest of our solar system was formed from a giant, rotating cloud of gas and dust known as the solar nebula.

As gravity caused the nebula to collapse, it spun faster and flattened into a disk. During this phase, most of the material was pulled toward the center to form the sun.

The Invisible Stuff in the Universe

This mysterious and invisible mass became known as dark matter.

Dark matter is inferred because of the gravitational pull it exerts on regular matter.

One hypothesis states that, the mysterious stuff could be formed by exotic particles that don't interact with light or regular matter.  
  
Dark matter is thought to make up 23 percent of the universe. In comparison, only 4 percent of the universe is composed of regular matter, which encompasses stars, planets and people.

## The Expanding and Accelerating Universe

In 1998, the prolific space telescope named after the famous astronomer, the Hubble Space Telescope, studied very distant supernovas and found that, a long time ago,

The universe was expanding more slowly than it is today. This discovery was surprising because it was long thought that the gravity of matter in the universe would slow its expansion, or even cause it to contract.

Dark matter and dark energy remain two of the biggest mysteries, but cosmologists continue to probe the universe in hopes of better understanding how it all began..