Aryabhat Astronomy Quiz

Study Material Part 3

The Big Bang

The universe formed some 12.5 billion years ago. Much is speculation, but somehow from a tiny speck everything including space, time, matter and energy unfolded into something that became recognizable as an early version of the universe we see about us today. Initially, the temperature was too intense to allow matter to condense from energy. All of the energy was in the form of fierce gamma radiation.

After expanding for many thousands of years, the temperature of the Universe had cooled to the point where gamma radiation could form neutrons, protons and electrons. Almost all of this matter was in the form of hydrogen (91+%) and helium (8%) and less than a percent lithium, an isotope of hydrogen (deuterium) and an isotope of helium (helium 3). Almost no other elements were created at this time. It is a matter of debate whether **primordial black holes** were also created. The forces were enough so that dense knots of matter could create black holes. These black holes may be the "seed" around which galaxies formed.

The Universe

Today large clouds of gas exist throughout the universe. Most of it is simple atoms, but some of these clouds contain simple molecules and dust. Most of it has collected in and around galaxies. While we see star formation throughout the universe, and we see the absorption of smaller galaxies when the encounter larger galaxies, we no longer see the formation of new galaxies.

The nature of the interstellar gas is very different today from the original gas. While hydrogen and helium still abound, other elements can be found in densities as high as 7%. This has profound consequences for the type of stellar systems that can form. Most importantly, heavy elements allow rocky planets such as the Earth to form. These new elements came from the transmutation of elements in the hearts of first generation stars. Elements up to iron in weight can be formed in normal stars and ejected into space as solar winds and exploding shells when the stars reach the red giant stage. Elements heavier than iron are created and distributed by a much more dramatic process - supernovas.

Star Formation

Stars are continually being formed from the huge reservoirs of hydrogen gas the fill the galaxies. It was once thought that gravity played the role of "gas compressor", but we now know that there hasn't been time since the formation of the universe to have many clouds compress naturally into stars. A triggering event is required. The two principle events are density waves and supernovae.

The center of every galaxy appears to contain a black hole. This is by no means certain, but something large and dense exists there. Lines of magnetic force stream outwards and are bent along the leading edges of the galactic arms. This creates a **density wave**, which sweeps up and compresses hydrogen and helium along with any other elements, which may be in the region. Although we cannot look down on the Milky Way to see such area, we can see similar areas in thousands of other galaxies. Along the leading edge of their arms, young fierce glowing blue white stars abound, a sure sign of star formation.

Stellar Luminosity

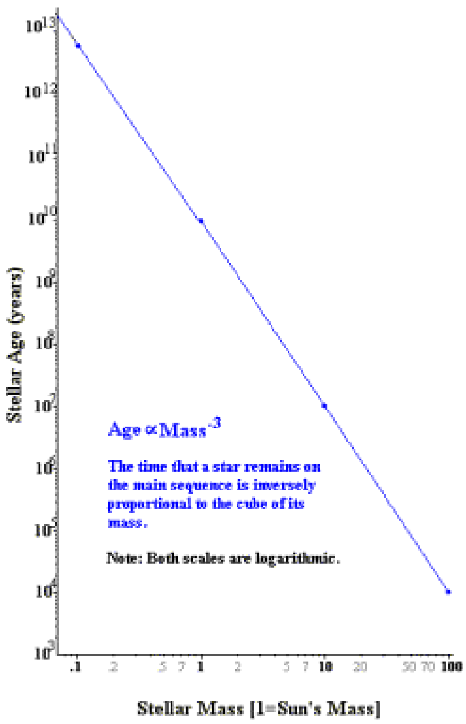
The luminosity (the total emitted energy) of a star is directly proportional to the fourth power of it mass. To maintain this power output, the star must consume its fuel proportional to its fourth power as well. If one main sequence star is 3 times as massive as another star, it will shine 81 times as brightly. It also fuses its fuel 81 times as rapidly. As stars leave the main sequence this relationship is disrupted.

The term luminosity is the preferred to describe the brightness of a star. For historical reason, the portion of a star's spectrum that lies in the visual range is measured by a magnitude scale. Stars of the first magnitude **seem** to be twice as bright as those of the second magnitude, which in turn seem to be twice as bright as those of the third magnitude. In fact, a closer relation ship is that every five magnitudes in brightness represent a 100-fold change in luminosity. Luminosity is measured directly. Magnitude is measured on an inverse logarithmic scale. Larger magnitudes mean dimmer stars, which is counterintuitive. Larger luminosities mean brighter stars exactly as you would think.

Do not confuse apparent luminosities with absolute luminosities. Apparent brightness depends on how a star looks to us on Earth. Absolute brightness depends on how bright a star would be at the standard distance of ten parsecs (33.26 light-years).

Stellar Lifetimes

The time that a star spends on the main sequence is INVERSELY proportional to the cube of its mass. This is a direct result of the luminosity relationship we just discussed. Since a stars luminosity (and hence its rate of fuel consumption) is proportional to the fourth power of the mass but its mass is only the first power, stars have a lifetime which is proportional to M/M^4 or simply M^{-3}.



Large stars have very short lifetimes. A maximal sized star of 100 solar masses will live 1 millionth as long as the Sun. A minimal sized star of 0.08 solar masses will live 1950 times than the Sun. Since the Sun will live about 10 billion years, the largest stars burn out in just about 10000 years but smallest stars will live 19.5 TRILLION years.

Stellar Classifications

When stars coalesce from interstellar gas clouds, their temperature and pressure rise from frictional heating and gravity. Once nuclear processes begin gas already falling in from the spinning disk collides with gas expanding from nuclear fusion. One way that **Herbig-Haro** stars relieve this problem is to eject mass at the poles of the new star.

Young stars have yet to achieve hydrostatic balance between the rate of energy production and the size of the star. As much as ten times the material that will eventually form the finished star exists in the new stellar system. This material must be driven back into the interstellar medium. Stars in this stage of development are called **T-Tauri** stars.

Brown dwarfs weighing between 0.01 and 0.08 stellar masses are neither true stars nor planets but intermediate objects. They radiate in the infrared. Most of their heat comes from gravitational contraction. However, sometimes their central cores are hot enough to fuse deuterium, lithium or beryllium. These elements fuse at a temperature several million degrees cooler than the minimum required for hydrogen fusion. However, there are so few of these atoms that they are unlike to encounter each other in a core that is largely hydrogen and helium. When these elements do fuse, they expand the core cooling it enough to shut down the reactions.

Once a body of hydrogen reaches 0.08 solar masses, it has enough material so that gravitational contraction will raise the central core to 15 million degrees. Hydrogen begins to fuse. A true star is born.

When the new star has a mass between 0.08 and 0.4 solar masses, it forms a small dim **red dwarf** star. Of the 100 nearest stars 92 are red dwarfs. They form in great numbers but their total luminosity is so low that galaxies seem blue white. Indeed, Proxima Centauri, the nearest star to the solar system is 13th magnitude - no brighter than dim little Pluto.

Most normal sized stars are the so-called **main sequence dwarfs**. They are in the spectral classes K, G, F and A with masses between 0.4 and 3.3 solar masses. The term "dwarf" is unfortunate because it seems to imply a star of small dimensions. In fact they are much larger and brighter than an average star. For example the Sun is a yellow G2 dwarf, yet of the 100 nearest stars only 3 are a bit larger and another is just a bit smaller. 95 stars have diameter, which are less than 60% of the Sun, and masses, which are less than 40% of the Sun. No nearby star is really large, although Sirius is almost twice the mass of the Sun. Some orange, yellow, white (green) stars fall into a category of **subgiants**. Subgiants are large stars, which are in the process of leaving the main sequence. These stars swell as the hydrogen fusion shell approaches the surface. Most of these stars are variables.

The largest main sequence stars are the **blue giants**. They are between 3.3 and 100 solar masses. While they are called blue giants, they can be blue, violet or even ultraviolet in color. These stars are extremely bright and short lived. Of the roughly 6000 stars that can be seen by the human eye, all but 50 are either red or blue giants. Blue giants of necessity are all very young stars. Some of these blue giants become unstable - like Dschubba and Gamma Cassiopeia - throwing off huge shells of gas and briefly becoming very bright. A few actually become supernovae without first becoming red giants.

Red giants posed a paradox to early astronomers. They were very red (hence they were cool) and they were very bright (which seemed impossible - because the black body laws [which we shall learn about in the Physics Section] say the red objects emit light dimly).

Finally, astronomers realized that a star with a very low brightness per square meter could actually put out a huge luminosity if its surface area was enormous.

Red giants have HUGE volumes although they have low density. A typical red giant like Antares or Betelgeuse will have a volume as large as the orbit of Mars. The largest known red giant VV Cassiopeia is calculated to have a diameter as large as the orbit of Saturn.

Red giants are aging stars, which have converted a large portion of their hydrogen to helium (typically 40-50%). As the core fills up with helium "ashes" the fusion zone approaches the surface. However at some point the gas above the star has too little remaining mass and the star stops being stable and begins to swell. The swollen star emits more light that before cooling it at a new less healthy stage. Red giants with lower mass (such as the Sun will become) will eventually simply become white dwarfs. High mass red giants are rapidly on their way to becoming supernova.

Class	Temperature (Kelvin)	Conventional color	Apparent color	Mass (solar masses)	Radius (solar radii)	Hydrogen lines
O	≥ 30,000 K	blue	blue	≥ 16	≥ 6.6	Weak
B	10,000–30,000 K	blue to blue white	blue white	2.1–16	1.8–6.6	Medium
A	7,500–10,000 K	white	white to blue white	1.4–2.1	1.4–1.8	Strong
F	6,000–7,500 K	yellowish white	white	1.04–1.4	1.15–1.4	Medium
G	5,200–6,000 K	yellow	yellowish white	0.8–1.04	0.96–1.15	Weak
K	3,700–5,200 K	orange	yellow orange	0.45–0.8	0.7–0.96	Very weak
M	≤ 3,700 K	red	orange red	≤ 0.45	≤ 0.7	Very weak

Stellar Instability : Variable stars

Eclipsing binaries are binary stars have the plane of their orbit edge on to the solar system. As the stars revolve around their barycenter they will regularly pass in front of one another. Since at least some of the total surface area is masked, the luminosity will drop. If one star is much brighter than its companion, there will be alternating large and small dips in the luminosity. By timing the dips precisely and determining the stars mass and velocity by applying Newton's laws of gravitation, it is possible to determine the diameters of the stars very accurately.

Flare stars appear to change more profoundly than they really do. All main sequence stars appear to emit flares. Against a bright star such as the Sun, Sirius or Rigil, a flare is lost in the overall brightness of the star. Against a dim red dwarf however, the flare can actually be brighter than the rest of the star's surface. All stars have flares where a pocket of overheated gas erupts at the surface. Momentarily, the star emits radiation of shorter wavelengths (blue, violet, ultra violet and x-rays). On a moderate star like the Sun, a flare tends to fade into surface brightness. Flares are unnoticeable on large blue stars. However, on a small red dwarf, a flare can actually be brighter than the star itself. For periods of a few minutes to a few hours the star may brighten several magnitude. Some amateurs watch a collection of red dwarfs looking for these flares.

Certain yellow orange subgiants (called **Cepheid variables**) pulsate in a very regular manner. It is possible to determine exactly how far these stars are from the solar system by timing the pulse rate. What makes these Cephied variables unusually useful is that they are bright enough to be seen in distant galaxies.

Hydrostatic balance is the balance between the expanding forces from the heat produced by fusion and compressive forces from gravity. Imbalances between the expansion and compression can cause pulsations. These stars expand when they are hottest, emit radiation more rapidly when they are inflated, cool and contract in a cycle. Cepheid variables are examples of pulsating stars.

Stellar Deaths :

Supernovae are the deaths of very large stars. Stars which start out at least 10 times the mass of the Sun cannot shed enough mass by ejecting shells by the time their core reaches 1.4 solar masses (Chandrashekhar's limit) [details to follow in Physics]. This results in an enormous explosion where all the elements of the periodic table beyond the first groups are produced. Supernovae can outshine their galaxy (billions and even trillions of star power) for a few weeks. Even this most titanic of nuclear explosions does not totally destroy the star. A core of compressed material remains. If the core is less than 1.4 solar masses it creates a white dwarf. If it is between 1.4 and 3 solar masses it forms a neutron star. More than 3 solar masses results in a black hole.

White dwarfs can result from supernovae, but they also are the end product of stars, which go through the red giant stage without going supernova. The sun will someday become a white dwarf after it swells into a red giant stage. You can see a white dwarf at the center of the Cat's Eye nebula.

White dwarfs no longer fuse hydrogen into helium. The core is composed of helium or some heavier element (usually, carbon, oxygen, neon, silicon, magnesium or sulfur). Since there is no steady source of fusion energy, white dwarfs slowly cool down eventually become cold inert [hundreds of trillions of years] black dwarfs. No white dwarf is believed to have entered black dwarf stage yet.

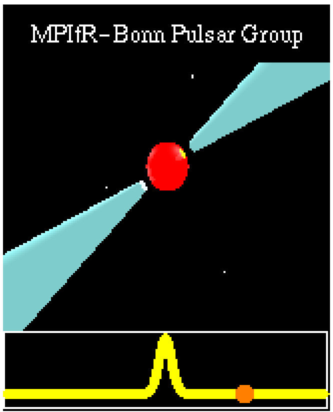
Astronomers used to think that **nova** and supernova were differing degrees of the same thing - stellar explosions. However, they are really quite dissimilar. Supernovae are titanic explosions, which rip stars scattering elements into the universe. Novae are recurring small explosions, which leave their "star" intact.

Novae are white dwarfs or neutron stars in close orbit around a main sequence star. The fierce gravity of the burnt out star strips the outer layers of hydrogen from the main sequence star. When enough accumulates on the burnt out star, a hydrogen bomb type explosion takes place.

We have already seen that **neutron stars** are supernovae remnants where the core is greater than 3 solar masses. These objects are very odd things indeed. In "normal" white dwarfs, the elements left after the supernova explosion, are left as plasma (sort of a gas where the electrons have been stripped away). The white dwarf does not have fusion energy to hold the star up from collapse, but the "electron pressure" (like charges repel) keeps the white dwarf steady at about the size of the planet Earth in diameter.

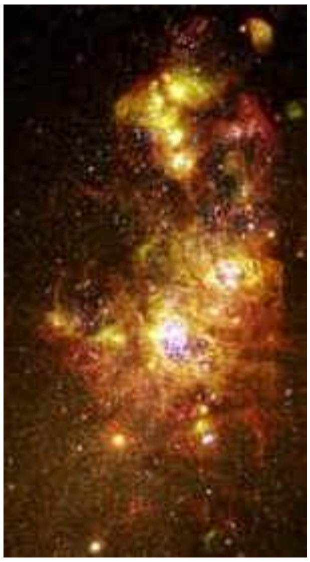
All this changes in neutron stars. Once the mass reaches 1.4 Sol, the gravity becomes so intense that the electrons are dragged kicking and screaming into the core. They get squished into the protons (positively charged nuclear particles) neutralizing them and becoming neutrons (uncharged nuclear particles). The star loses the pressure of the "degenerate electrons" and it collapses into a ball about 10 miles in diameter spinning at hundreds and thousands of times per second. The surface of a neutron star spins very near the speed of light.

Effectively, this neutron star is a single giant (fiercely radioactive) atom. It is very nearly the densest object in the universe. A sugar cube chunk of this stuff would weigh more that Mount Everest.



Pulsars (a type of neutron star) spin extremely rapidly. Near their poles, they emit charged particles at very near the speed of light. Think of them as swizzle sticks spinning around blindingly fast. The swizzle sticks of charged particles sweep up and stir around the gas in the system they reside in causing a form of electromagnetic radiation. Some of this is in the radio frequencies and the rest in higher frequencies up to visible flashes. If the beam of charged particles is lined up in the direction of the Solar system, the electromagnetic radiation will flash on us. When these very regular flashes were first detected many astronomers suspected they were artificially produced by alien species.

Supernova remnants greater than 3 solar masses cannot remain stable at the neutron star stage. They become the most exotic of all stellar objects - **black holes**. Gravity again begins its relentless pull. The gravity reaches a point where no particles, not even light can escape because they would have to travel above the speed of light (the universal maximum) to leave the ex-star. [There is an odd form of radiation (Hawking radiation) which can leave the event horizon of a black hole through quantum mechanical processes but we will not discuss it here].



Role of Supernovae

We are such things as dreams are made on," said Shakespeare. I wonder what he would have said if he realized that it is also quite literally true that once our very elements were forged in the hearts of the largest stars. Look at the Crab Nebula as the explosion, which tore it apart, sends material through space. However, the material which pours out of a supernova is not just the hydrogen and helium which formed the star but nitrogen, oxygen, carbon, silicon, sulfur, magnesium, neon, iron and in fact to some degree or other every element in the natural world.

One role of a supernova is to create the elements from which Population I (metal rich) stars are formed. These are the stars that can have rocky, watery worlds where life can form. The other crucial role that supernova play is becoming another source of gas compression and the triggering of new stars. Like density waves, the bow wave of a supernova explosion pushes everything before it and compresses gas until its own gravity can take over forming a new set of stars.

For our purposes, the event horizon marks the point where anything that enters the black hole cannot leave. There is a false belief that black holes are all powerful vacuums, which slurp anything and everything into their maw. This is not so. For example if you squeezed the Earth into a black hole (an event horizon about the size of a marble), and stood at a distance of 6,400 kilometers from it (our current distance from the center of the Earth) the gravity would be exactly 1 G. The field would only become great as we came very close to the black hole.

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Some useful terms & definitions

Asteroids : Asteroids (sometimes called planetoid) are planetesimals, which orbit a star. Ideally, all asteroids would be planetesimals, however some larger asteroids are actually worlds. The dividing line is an arbitrary 1000 km.

Brightness : A measure of a star's magnitude or brightness as seen from the Earth. Brightness is dependent on luminosity and distance.

Degrees : The separation between two points of light on the celestial sphere is measured in degrees. A closed fist held at arms length is about 10 degrees while a finger would be 1 degree or two moon widths.

Dwarf Stars : Dwarfs are regular stars like the Sun, which have modest masses and modest volumes. Stars, which are not some sort of “giant”, are called dwarfs no matter what their size. super dense star is called a white or a black dwarfs.

Giant Stars : Giant Stars have volumes many thousands of times that of the Sun. Some "sub-giants" and "blue giants" have masses much greater than the Sun, but volumes, which are not radically larger than the Sun.

Luminosity : The intrinsic brightness of a star -- as it would appear if you orbiting it -- compared to the Sun. The Sun's luminosity is 1. Sirius has a luminosity of 23 and Betelgeuse 55, 000.

Magnitude : A logarithmic brightness scale, the difference between magnitude 1 and magnitude 5 is 100 fold. The larger the magnitude, the fainter the object. The lower the magnitude, the brighter the object. The brightest stars have negative magnitudes.

Main Sequence Stars : Main Sequence Stars are huge bodies, which derive the vast majority of their energy primarily from fusing hydrogen to helium. Main sequence stars are in *hydrostatic balance* between the forces of gravity and nuclear fusion. Stars too young to have achieved this balance throw off huge amounts of material via jets and fierce solar winds. Stars that have used up their hydrogen fuel supply swell enormously.

Planetesimals : Planetesimals are bodies, which is too small to attain spherical shape simply through their own gravity. A planetesimal melted by passing too close to a star and becoming spherical due to surface tension (a result of electromagnetic force) does not count, because the forming was not done primarily by gravity.

Rogues : Rogues are suspected (but unproven) worlds like planets that do not orbit stars. These are believed to be ejected from star systems as the systems grow older. See Planets.

Satellites : Satellites (often called moons) are either worlds or planetesimals, which orbits a planet.

Worlds : Worlds are bodies large enough to be pulled into roughly spherical shape by their own gravity. All stars fall within this definition as do major planets and large moons.

Milestones in Indian Space Research	
2018	PSLV-C41 Successfully Launches IRNSS-1I Navigation Satellite
	GSLV Successfully Launches GSAT-6A Satellite
	PSLV Successfully Launches 31 Satellites in a Single Flight
2017	India's GSAT-17 Communication Satellite Launched Successfully
	PSLV-C38 Successfully Launches 31 Satellites in a Single Flight
	First Developmental Flight of India's GSLV MkIII launches GSAT-19 Satellite
	GSLV Successfully Launches South Asia Satellite
	PSLV-C37 Successfully Launches 104 Satellites in a Single Flight
2016	PSLV-C36 Successfully Launches RESOURCESAT-2A Remote Sensing Satellite
	India's GSAT-18 Communication Satellite Launched Successfully
	PSLV-C35 Launches Eight Satellites into Two Different Orbits in a Single Flight
2016	GSLV Successfully Launches India's Weather Satellite INSAT-3DR
	PSLV-C34 Successfully Launches 20 Satellites in a Single Flight
	India's Reusable Launch Vehicle (RLV-TD), Flight Tested
2016	PSLV-C33 Successfully Launches India's Seventh Navigation Satellite IRNSS-1G
	PSLV-C32 Successfully Launches India's Sixth Navigation Satellite IRNSS-1F
	PSLV-C31 Successfully Launches India's Fifth Navigation Satellite IRNSS-1E
2015	India's GSAT-15 Communication Satellite Launched Successfully
	Book released on the Second Anniversary of Mars Orbiter Spacecraft Launch
	PSLV Launches India's Multi Wavelength Space Observatory ASTROSAT
	Indigenously Developed High Thrust Cryogenic Rocket Engine Ground Tested
	PSLV Successfully Launches Five Satellites from UK
	PSLV-C27 Successfully Launches India's Fourth Navigation Satellite IRNSS-1D

Milestones in Indian Space Research	
2014	PSLV-C23 launches SPOT 7 and four co-passenger satellites from Sriharikota
	PSLV - C24 successfully launches IRNSS-1B from Sriharikota (Apr 04, 2014)
	GSLV-D5 successfully launches GSAT-14 from Sriharikota (Jan 05, 2014)
2013	PSLV - C25 successfully launches Mars Orbiter Mission Spacecraftfrom Sriharikota (Nov 05, 2013)
	Successful launch of GSAT-7 by Ariane-5 VA-215 from Kourou French Guiana (August 30, 2013)
	Successful launch of INSAT-3D by Ariane-5 VA-214 from Kourou French Guiana (July 26, 2013)
	PSLV - C22 successfully launches IRNSS-1A from Sriharikota (Jul 01, 2013)
	PSLV - C20 successfully launches SARAL and six commercial payloadsfrom Sriharikota (Feb 25, 2013)
2012	Successful launch of GSAT-10 by Ariane-5 VA-209 from Kourou French Guiana (September 29, 2012)
	ISRO's Polar Satellite Launch Vehicle, PSLV-C21 successfully launches SPOT 6 and PROITERES from Sriharikota (September 09, 2012)
	PSLV-C19 successfully launches RISAT-1 from Sriharikota (April 26, 2012)
2011	PSLV-C18 successfully launches Megha-Tropiques, Jugnu, SRMSat andVesselSat-1 from Sriharikota (October 12, 2011)
	PSLV-C17 successfully launches GSAT-12 from Sriharikota (July 15, 2011)
	Successful launch of GSAT-8 by Ariane-5 VA-202 from Kourou French Guiana, (May 21, 2011)
	PSLV-C16 successfully launches Three Satellites - RESOURCESAT-2,YOUTHSAT, X-SAT from Sriharikota (April 20, 2011)
2010	GSLV-F06 launched from Shriharikota (Dec 25, 2010). GSAT-5P could not be placed into orbit as the GSLV-F06 mission was not successful
	Successful launch of advanced communication satellite HYLAS (Highly Adaptable Satellite), built by ISRO on a commercial basis in partnership with EADS-Astrium of Europe, by Ariane-5 V198 from Kourou French Guiana (November 27, 2010)

Milestones in Indian Space Research	
	PSLV-C15 successfully launches Five Satellites - CARTOSAT-2B, ALSAT-2A, two nanosatellites-NLS-6.1 & 6.2 and a pico-satellite- STUDSAT from Sriharikota (July 12, 2010)
	GSLV-D3 launched from Sriharikota (Apr 15, 2010). GSAT-4 satellite could not be placed in orbit as flight testing of the Indigenous Cryogenic Stage in GSLV-D3 Mission was not successful
2008	PSLV-C9 successfully launches CARTOSAT-2A, IMS-1 and 8 foreign nano satellites from Sriharikota (April 28, 2008) PSLV-C10 successfully launches TECSAR satellite under a commercial contract with Antrix Corporation (January 21, 2008)
2007	Successful launch of of GSLV (GSLV-F04) with INSAT-4CR on board from SDSC SHAR (September 2, 2007) ISRO's Polar Satellite Launch Vehicle, PSLV-C8, successfully launched Italian astronomical satellite, AGILE from Sriharikota (April 23, 2007). Successful launch of INSAT-4B by Ariane-5 from Kourou French Guyana, (March 12, 2007). Successful recovery of SRE-1 after manoeuvring it to reenter the earth’s atmosphere and descend over the Bay of Bengal about 140 km east of Sriharikota (January 22, 2007). ISRO's Polar Satellite Launch Vehicle, PSLV-C7 successfully launches four satellites - India’s CARTOSAT-2 and Space Capsule Recovery Experiment (SRE-1) and Indonesia’s LAPAN-TUBSAT and Argentina’s PEHUENSAT-1 (January 10, 2007).
2006	Second operational flight of GSLV (GSLV-F02) from SDSC SHAR with INSAT-4C on board. (July 10, 2006). Satellite could not be placed in orbit.
2005	Successful launch of INSAT-4A by Ariane from Kourou French Guyana, (December 22, 2005). ISRO's Polar Satellite Launch Vehicle, PSLV-C6, successfully launched CARTOSAT-1 and HAMSAT satellites from Sriharikota(May 5, 2005).
2004	The first operational flight of GSLV (GSLV-F01) successfully launched EDUSAT from SDSC SHAR, Sriharikota (September 20, 2004)

Milestones in Indian Space Research	
2003	ISRO's Polar Satellite Launch Vehicle, PSLV-C5, successfully launched RESOURCESAT-1 (IRS-P6) satellite from Sriharikota(October 17, 2003). Successful launch of INSAT-3E by Ariane from Kourou French Guyana, (September 28, 2003). The Second developmental launch of GSLV-D2 with GSAT-2 on board from Sriharikota (May 8, 2003). Successful launch of INSAT-3A by Ariane from Kourou French Guyana, (April 10, 2003).
2002	ISRO's Polar Satellite Launch Vehicle, PSLV-C4, successfully launched KALPANA-1 satellite from Sriharikota(September 12, 2002). Successful launch of INSAT-3C by Ariane from Kourou French Guyana, (January 24, 2002).
2001	ISRO's Polar Satellite Launch Vehicle, PSLV-C3, successfully launched three satellites -- Technology Experiment Satellite (TES) of ISRO, BIRD of Germany and PROBA of Belgium - into their intended orbits (October 22, 2001). The first developmental launch of GSLV-D1 with GSAT-1 on board from Sriharikota (April 18, 2001)
2000	INSAT-3B, the first satellite in the third generation INSAT-3 series, launched by Ariane from Kourou French Guyana, (March 22, 2000).
1999	Indian Remote Sensing Satellite, IRS-P4 (OCEANSAT), launched by Polar Satellite Launch Vehicle (PSLV-C2) along with Korean KITSAT-3 and German DLR-TUBSAT from Sriharikota (May 26, 1999). INSAT-2E, the last satellite in the multipurpose INSAT-2 series, launched by Ariane from Kourou French Guyana, (April 3, 1999).
1998	INSAT system capacity augmented with the readiness of INSAT-2DT acquired from ARABSAT (January 1998).
1997	INSAT-2D, fourth satellite in the INSAT series, launched (June 4, 1997). Becomes inoperable on October 4, 1997. (An in-orbit satellite, ARABSAT-1C, since renamed INSAT-2DT, was acquired in November 1997 to partly augment the INSAT system). First operational launch of PSLV with IRS-1D on board (September 29, 1997). Satellite placed in orbit.
1996	Third developmental launch of PSLV with IRS-P3 on board (March 21, 1996). Satellite placed in polar sunsynchronous orbit.

Milestones in Indian Space Research	
1995	Launch of third operational Indian Remote Sensing Satellite, IRS-1C (December 28, 1995).
	INSAT-2C, the third satellite in the INSAT-2 series, launched (December 7, 1995).
1994	Second developmental launch of PSLV with IRS-P2 on board (October 15, 1994). Satellite successfully placed in polar sunsynchronous orbit.
	Fourth developmental launch of ASLV with SROSS-C2 on board (May 4, 1994). Satellite placed in orbit.
1993	First developmental launch of PSLV with IRS-1E on board (September 20, 1993). Satellite could not be placed in orbit.
	INSAT-2B, the second satellite in the INSAT-2 series, launched (July 23, 1993).
1992	INSAT-2A, the first satellite of the indigenously-built second-generation INSAT series, launched (July 10, 1992).
	Third developmental launch of ASLV with SROSS-C on board (May 20, 1992). Satellite placed in orbit.
1991	Second operational Remote Sensing satellite, IRS-1B, launched (August 29, 1991).
1990	INSAT-1D launched (June 12, 1990).
1988	INSAT-1C launched (July 21, 1988). Abandoned in November 1989.
	Second developmental launch of ASLV with SROSS-2 on board (July 13, 1988). Satellite could not be placed in orbit.
	Launch of first operational Indian Remote Sensing Satellite, IRS-1A (March 17, 1988).
1987	First developmental launch of ASLV with SROSS-1 satellite on board (March 24, 1987). Satellite could not be placed in orbit.
1984	Indo-Soviet manned space mission (April 1984).
1983	INSAT-1B, launched (August 30, 1983).
	Second developmental launch of SLV-3. RS-D2 placed in orbit (April 17, 1983).
1982	INSAT-1A launched (April 10, 1982). Deactivated on September 6, 1982.

Milestones in Indian Space Research	
1981	Bhaskara-II launched (November 20, 1981). APPLE, an experimental geo-stationary communication satellite successfully launched (June 19, 1981). RS-D1 placed in orbit (May 31, 1981) First developmental launch of SLV-3.
1980	Second Experimental launch of SLV-3, Rohini satellite successfully placed in orbit. (July 18, 1980).
1979	First Experimental launch of SLV-3 with Rohini Technology Payload on board (August 10, 1979). Satellite could not be placed in orbit. Bhaskara-I, an experimental satellite for earth observations, launched (June 7, 1979).
1977	Satellite Telecommunication Experiments Project (STEP) carried out.
1975-1976	Satellite Instructional Television Experiment (SITE) conducted.
1975	ISRO First Indian Satellite, Aryabhata, launched (April 19, 1975). Becomes Government Organisation (April 1, 1975).
1972-1976	Air-borne remote sensing experiments.
1972	Space Commission and Department of Space set up (June 1, 1972). ISRO brought under DOS.
1969	Indian Space Research Organisation (ISRO) formed under Department of Atomic Energy (August 15, 1969).
1968	TERLS dedicated to the United Nations (February 2, 1968).
1967	Satellite Telecommunication Earth Station set up at Ahmedabad.
1965	Space Science & Technology Centre (SSTC) established in Thumba.
1963	First sounding rocket launched from TERLS (November 21, 1963).
1962	Indian National Committee for Space Research (INCOSPAR) formed by the Department of Atomic Energy and work on establishing Thumba Equatorial Rocket Launching Station (TERLS) started.

Observational Opportunities

Largest Telescopes :

Name	Aperture		Mirror type	Nationality / Sponsors	Location
	mtr	inch			
Gran Telescopio Canarias	10.4 m	409″	Segmented, 36	Spain (90%), Mexico, USA	Canary Islands
Keck 1	10 m	394″	Segmented, 36	USA	Hawaii
Keck 2	10 m	394″	Segmented, 36	USA	Hawaii
Southern African Large Telescope	9.2 m	362″	Segmented, 91	South Africa, USA, UK, Germany, Poland, New Zealand	South Africa
Hobby-Eberly Telescope	9.2 m	362″	Segmented, 91	USA, Germany	Texas
Large Binocular Telescope	8.4 m × 2	330″ × 2	Multiple mirror, 2	USA, Italy, Germany	Arizona
Subaru	8.2 m	323″	Single	Japan	Hawaii
VLT UT1 (Antu)	8.2 m	323″	Single	ESO Countries, Chile	Chile
VLT UT2 (Kueyen)	8.2 m	323″	Single	ESO Countries, Chile	Chile
VLT UT3 (Melipal)	8.2 m	323″	Single	ESO Countries, Chile	Chile
VLT UT4 (Yepun)	8.2 m	323″	Single	ESO Countries, Chile	Chile
Gemini North (Gillett)	8.1 m	318″	Single	USA, UK, Canada, Chile, Australia, Argentina, Brazil	Hawaii
Gemini South	8.1 m	318″	Single	USA, UK, Canada, Chile, Australia, Argentina, Brazil	Chile
MMT	6.5 m	256″	Single	USA	Arizona
Magellan 1 (Walter Baade)	6.5 m	256″	Honeycomb	USA	Chile
Magellan 2 (Landon Clay)	6.5 m	256″	Honeycomb	USA	Chile
BTA-6	6 m	238″	Single	USSR/Russia	Russia
Large Zenith Telescope	6 m	236″	Liquid	Canada, France, USA	British Columbia
Hale Telescope	5.08 m	200″	Single	USA	California
LAMOST	4.9 m	193″	Segmented (37 + 24)	PRC (China)	Xinglong, China
MMT	4.7 m	186″	Segmented, 6	USA	Arizona
Discovery Channel Telescope	4.3 m	169″	Single	USA	Arizona
William Herschel Telescope	4.2 m	165″	Single	UK, Netherlands, Spain	Canary Islands
SOAR	4.1 m	161″	Single	USA, Brazil	Chile
VISTA	4.1 m	161″	Single	ESO Countries, Chile	Chile
Victor M Blanco Telescope	4 m	157″	Single	USA	Chile
Nicholas U Mayall	4 m	149.5″	Single	USA	Arizona
Anglo-Australian Telescope	3.89 m	154″	Single	Australia, UK	New South Wales
AEOS Telescope	3.67 m	145″	Single	USA	Hawaii
Telescopio Nazionale Galileo	3.58 m	138″	Single	Italy	Canary Islands
New Technology Telescope	3.58 m	142″	Single	ESO countries	Chile
Canada-France-Hawaii Telescope	3.58 m	141″	Single	Canada, France, USA	Hawaii
ESO 3.6 m Telescope	3.57 m	140″	Single	ESO countries	Chile
MPI-CAHA	3.5 m	138″	Single	West Germany, Spain	Almería, Spain
USAF Starfire	3.5 m	138″	Single	USA	New Mexico
WIYN Telescope	3.5 m	138″	Single	USA	Arizona
Space Surveillance Telescope	3.5 m	138″	Single	USA	New Mexico
Astrophysical Research Consortium	3.48 m	137″	Single	USA	New Mexico
Shane Telescope	3.05 m	120″	Single	USA	California
NASA Infrared Telescope Facility	3.0 m	120″	Single	USA	Hawaii
NASA-LMT	3 m	118″	Liquid	USA	New Mexico

High Altitude Telescopes :

Observatory Name	Elevation	Location	Coordinates	Type of Observatory
University of Tokyo Atacama Observatory(TAO)	5,640 m	Atacama Desert, Chile	22°59′12″S 67°44′32″W	Optical, infrared
Chacaltaya Astrophysical Observatory	5,230 m	Andes, Bolivia	16°21′12″S 68°07′53″W	Cosmic ray, gamma ray
James Ax Observatory	5,200 m	Atacama Desert, Chile	22°57′30″S 67°47′10″W	Microwave
Atacama Cosmology Telescope	5,190 m	Atacama Desert, Chile	22°57′31″S 67°47′16″W	Microwave
Llano de Chajnantor Observatory	5,104 m	Atacama Desert, Chile	23°01′22″S 67°45′17″W	Millimeter wave, submillimeter
Shiquanhe Observatory (NAOC Ali Observatory)	5,100 m	Tibet Autonomous Region, China	32°19′N 80°01′E	Optical
Llano de Chajnantor Observatory	4,800 m	Atacama Desert, Chile	22°58′17″S 67°42′10″W	Submillimeter
Large Millimeter Telescope Alfonso Serrano	4,580 m	Puebla, Mexico	18°59′06″N 97°18′53″W	Microwave
Indian Astronomical Observatory	4,500 m	Hanle, Ladakh, India	32°46′46″N 78°57′51″E	Infrared, gamma ray, Optical[14]
Meyer-Womble Observatory	4,312 m (14,148 ft)	Colorado, United States	39°35′12″N 105°38′24″W	Optical, Infrared
Yangbajing International Cosmic Ray Observatory	4,300 m	Tibet Autonomous Region, China	30°05′N 90°33′E	Cosmic ray
Mauna Kea Observatory	4,190 m	Hawaii, United States	19°49′28″N 155°28′24″W	Optical, infrared, submillimeter
High-Altitude Water Cherenkov (HAWC) Gamma-Ray Observatory	4,100 m	Puebla, Mexico	18°59′40″N 97°18′33″W	Gamma ray
Barcroft Observatory	3,890 m	California, United States	37°35′19″N 118°14′31″W	Infrared, millimeter wave
Very Long Baseline Array (VLBA), Mauna Kea Site	3,730 m	Hawaii, United States	19°48′05″N 155°27′20″W	Radio telescope
Llano del Hato National Astronomical Observatory	3,600 m	Andes, Venezuela	8°47′11″N 70°52′19″W	Optical telescope
Sphinx Observatory	3,571 m	Bernese Alps, Switzerland	46°32′51″N 7°59′6″E	Optical telescope
Mauna Loa Observatory	3,394 m	Hawaii, United States	19°32′10″N 155°34′34″W	Optical, millimeter wave
Magdalena Ridge Observatory	3,230 m	New Mexico, United States	33°58′36″N 107°11′05″W	Optical, infrared
Mount Graham International Observatory	3,191 m	Arizona, United States	32°42′05″N 109°53′31″W	Optical, submillimeter
Gornergrat Observatory	3,135 m	Pennine Alps, Switzerland	45°59′04″N 7°47′09″E	Infrared, submillimeter
Haleakala Observatory	3,036 m	Hawaii, United States	20°42′30″N 156°15′27″W	Optical, millimeter wave