Seeing the Visible and the Invisible of Space

Dipankar Ghosh

Physics Department, Serampore College, Serampore, Dist: Hooghly, PIN – 712201

Date of Submission: 9th March, 2016 Date of Acceptance: 24th March, 2016

Abstract

The discovery of telescope changed forever the way we looked at the Universe. Our idea about space, as was perceived through the naked eye, was revolutionized. The continuous upgrading of the telescopes over the years and subsequent advancements of the sciences of Astronomy and Astrophysics experienced another big leap with the launching of the space telescopes in the 20th century. Now the space could be perceived both through the visible and invisible electromagnetic waves. Launch of "ASTROSAT" by ISRO is perhaps the next possible leap that could be. An overview of all these developments is presented here.

1. Introduction

Research in the subjects of Astronomy and Astrophysics without the use of telescopes is unimaginable. Telescopes have undergone remarkable developments over the last 400 years. Although ground based observations done in the visible part of the electromagnetic spectra have undergone radical improvement in the last century its limitations are unavoidable. Advancements in Astronomy and Astrophysics have raised the necessary demand in due course of scrutinizing of the different cosmic events and entities through other parts of the electromagnetic spectra. Such limitations and demand have lead to the development of the space observatories and/or space telescopes. The era of space observatories began way back in 1970 and the launching of Hubble Space Telescope (HST) in 1990 by NASA was perhaps the most important landmark in this age of space telescopes. This has been followed, almost in no time, by several telescopes and observatories to cater the need of observing the space through both visible and other "invisible" parts of the electromagnetic spectra. India is not far behind in this new era. The recent launch of the "ASTROSAT" by ISRO is a clear indication of that. Here an overview on these pursuits of space observations through the space telescopes and observatories has been presented emphasizing on the relevance of ASTROSAT.

Under section "Discussion" the sub-section1 titled "Ground Frontier" describes briefly, how the terrestrial methods of observation of space have progressed over the years. Sub-section– (ii) titled "Different Sources and their Wide Band of Electromagnetic Radiation" provides an outline of various cosmic events and the associated electromagnetic radiations. Sub-section–(iii) discusses the space observatories under title “Space Frontier”. ASTROSAT is covered in the separate sub–section–(iv) where its various instruments and their capabilities are emphasized upon. Finally in concluding the uniqueness of ASTROSAT mission is underlined.

2. Discussion

i) The Ground Frontier

Refractive type telescope: The year 1608 was marked by several successful constructions of telescope like instruments and the ones constructed by Hans Lipperhay and Joseph Meitus demands special mention in this respect. Meitus being awarded the first patent for an instrument for “seeing faraway things as though nearby”[1,2], can well be considered to be the true inventor of the telescope. Galileo’s instrument which he had used in the later part of 1609 to make several astounding astronomical discoveries was evidently a more powerful one than anything his predecessors used. So, the telescope, in the present context as an optical instrument for making astronomical observations, can very well be considered to be an invention Galileo. Looking back from the present date, even Galileo’s telescope, belonging to the category of refractive telescopes, is found to be very basic in design and function. With time refractive telescopes of better magnification were developed which required bigger objective lenses. But manufacturing of primary lenses bigger than 4 inch in diameter was very difficult in those early days. During the late 1700s and early 1800s lens manufacturing by glass casting method provided a necessary breakthrough. Much bigger and flawless achromatic lenses could be made available using this method. But the problem of stabilizing big lenses through clamping by its rim was still at large. Moreover, the bigger and thicker lenses used for better magnification absorbed a major portion of the incident light affecting the intensity of the resulting image. So by the end of the 19th century, most of the observatories shifted from the refractive type of telescope to the reflective type[3].

Reflective type telescope: Sir Isaac Newton invented the reflective telescope in 1668. Newton’s telescope was only six inches in length but provided magnification as good as the refractors that were 3 to 6 feet long. The reflectors were inherently free from chromatic aberration and the problem of spherical aberration could be solved by using curved parabolic mirrors instead of spherical ones. Metal alloy mirrors tarnished quickly and required frequent cleaning and polishing. During 1850s a German chemist, Justus von Liebig made a new kind of mirror by depositing a glass surface with a thin film of silver. Silver, being a noble metal didn’t tarnish easily.

Atmospheric distortion and adaptive optics: By the beginning of the 20th century the reflective type of telescopes, for its easy maneuverability and stability, were preferred over the refractive type. However, observations made by both these telescopes were maligned with the effects of atmospheric distortion. The uneven heating of the atmosphere, the non–uniform accumulation of water molecules and the suspended dust particles in the atmosphere are the primary reasons behind this atmospheric distortion. The well known effect of "twinkling" of the stars pose a big problem for ground based observations. In addition to that, dropping of intensity due to atmospheric absorption and the ever increasing terrestrial stray light sources made ground observations difficult. Reflectors with multiple primary mirrors improved the intensity and building observatories in secluded area could free observations from stray light disturbances. But the problem of atmospheric distortion was still at large. Horace W. Babcock, an astronomer at the Mount Wilson Observatory in his seminal paper in 1953[4,5] proposed for the first time a remedy. His idea was to distort the reflective surface at specific locations and instances just enough to compensate the effect of atmospheric distortion. It was only during the 1970s that Babcock's ideas could be applied; a whole new field of "adaptive optics" was underway. Figs. 1 and 2 illustrate the problem of atmospheric distortion and remedies of the same by means of adaptive optics.

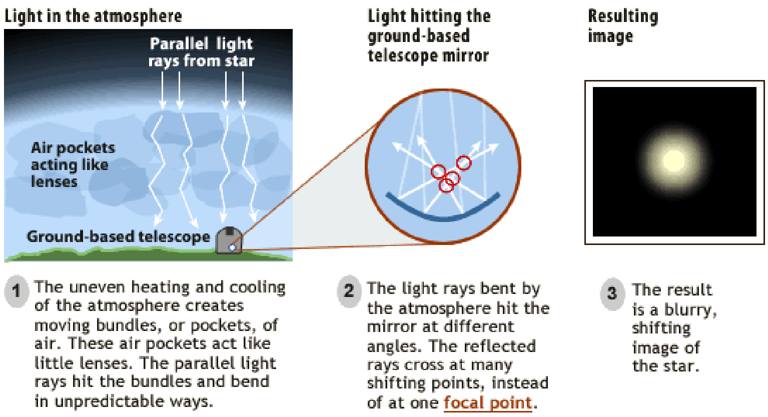

Fig.1, The effect of atmospheric distortion and its results (courtesy: www.stsci.edu)

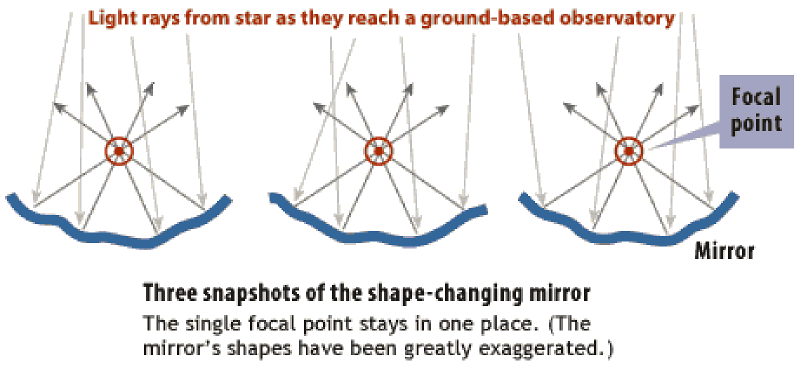

Fig.2, The basic idea behind adaptive optics (courtesy: www.stsci.edu)

Employing adaptive optics the terrestrial observations through the visible part of the electromagnetic spectra could be improved sharply. The universe however dispatches information about all its events through signals spread out in every part of the electromagnetic spectrum. A brief account of this has been given in the next sub–section.

ii) Different Sources of the Universe and their Wide Band of Electromagnetic Radiation

A Basic Account of the Physical Processes Involved in the Formation of Stellar and Other Structures in the Universe: In the expanding universe the formation of structures like stars, galaxies and cluster of galaxies is mainly governed by the opposing actions of gravitation and pressure. The gravitational collapse of an interstellar or protogalactic cloud causes its density to rise which subsequently raises the pressure and temperature of its inner regions. Such rise of pressure opposes the collapse.

James Jeans, an English astronomer in 1902, in his famous publication[6] proposed a criterion that will enable these two opposing entities to achieve a balance in a spherical nebula. According to this criterion, if the radius of the cloud of interstellar material is greater than a critical value called the Jean's critical length, the gravitational collapse will continue. Only when the radius becomes comparable to the Jean's critical length, the thermal pressure is strong enough to counterbalance the gravitational collapse. This length however is inversely proportional to the density of the matter involved. So an increase in density due to the collapse not only increases the thermal pressure but it also results into a rapid drop of the jeans length. The radius and the Jean's critical length of the cloud race against each other in the process of collapse. For a very large and massive bulk the drop of Jean's critical length is faster and this leads to gravitational condensations about multiple centre resulting into fragmentation of the bulk and further collapse of each such fragments simultaneously.

During such collapse and fragmentation the thermal pressure build up is hindered due to loss of energy from the interior of the bulk as electromagnetic radiation. Continuous increase of density at some point reduces such radiation loss considerably. Though the individual fragments continue to collapse, from this point on further fragmentation is stopped. Surely the collapse now continues at a slower rate due to the rapid rise of temperature of the interiors. Now, gradually the radius of the fragments catches up with the jeans length. The temperature of these individual protostar like fragments eventually reach a value where the H to He thermonuclear reaction is initiated, a star is born. There is further rise of temperature of the core and the star is capable of emitting radiation in a wide band of frequencies.

The Red Giant, White Dwarf, Neutron Star and the Black Hole: Stars can have broadly three kinds of fate. Stars like the Sun gradually burn out their hydrogen reserves. The gravitational collapse continues resulting into a rise of temperature of the core. But such rise is not enough to initiate the 3 He to C thermonuclear reaction. However, the temperature of the layers adjacent to the core now becomes high enough to initiate the H to He reactions in them. As a result of this the layer expands, has a drop of temperature, emits in the longer wavelength band and becomes a red giant. Gradually, the outer layers are given off in the form of planetary nebula and the core by then has undergone enough gravitational collapse to attain a higher temperature to initiate the 3 He to C thermonuclear reaction. Radiating in such high temperatures the star appears white and its reduced size gives it a name white dwarf. The white dwarves continue to radiate as long as their fuel is not consumed. The gravitational collapse in them comes to a halt due to pressure arising from electron degeneracy[7–9].

For stars having exceeded the Chandrasekhar limit (~1.4 times the Solar mass i.e. 1.988 X 10^{30} kg)[8,9] the collapse is not halted at this point. In such stars thermonuclear reactions other than the ones already mentioned take place. Nuclei of different elements are formed in the different layers. The gravitational collapse of the core is so strong that it fuses the electrons and proton to form neutrons. The neutron degeneracy pressure now stops further collapse, the core recoils back to the outer layer which is then given off in a huge explosion. A shower of radiation and neutrinos is given out and a peak luminosity of about 10^9 times that of Sun (3.828 X 10^{26} $Jsec^{-1}$) is reached. This is called a supernova of type–II. The core is now a neutron star. Very high temperatures prevail in these neutron stars. But further gravitational collapse is stalled due to neutron degeneracy.

Stars which are more than twice the Sun's mass go beyond forming neutron stars. In them, after the nuclear fuel is consumed, the gravitational collapse continues irreversibly giving birth to a black hole. The white dwarves, neutron stars and the black holes come under the class called the compact objects.

All these processes taking place in the universe evidently gives rise to a wide range of temperatures. Acceleration of the free and bound charges of matter at any temperature higher than absolute zero results into emission of radiation in different frequency bands and higher the temperature higher the acceleration of the charges. Such rapid acceleration of charges causes emission of radiation at higher energies and frequencies. Thus a stellar or a galactic source having temperatures ~10^3K would emit in the visible range (wavelength = 400nm–700 nm) while a source at temperatures ~10^6K would start emittting X–rays (0.001nm–10 nm). Temperatures in between (~10^5K) these values would produce radiation in the UV range (10nm–400nm).

Pulsars and Accretion Phenomena: There are also processes that cause periodic or aperiodic variation of the radiation intensities. Neutron stars which have strong magnetic fields (almost trillion times stronger than Earth's own field of ~0.5 Gauss) have such periodic variations associated with them. The neutron star being a compact high density object may rotate very fast about its axis and this axis of rotation is generally misaligned with its magnetic axis. This combination of a strong magnetic field and rapid rotation gives rise to electric fields strong enough to rip charged particles away from the surface of a neutron star. The charged particles steered by the magnetic field lines are accelerated only towards the magnetic poles thus causing intense but narrow **beams** of radiation to be emitted only from the two magnetic poles. This gives the beacon like appearance to neutron stars. Such beacon like periodic variation of radiation intensities from neutron stars has given them the name Pulsars[10–13].

At various stages and different scales stellar and other cosmic entities get involved in accretion or accumulation of materials from its neighborhood due to its stronger gravitational field. Such accretions which are common features associated with binary stars (generally binaries comprise of a compact object and a main stream star) and super massive black holes generally found at galaxy centre (such galaxy centre are called Active Galactic Nuclei) are as good as gravitational free falls. Such free falls cause high temperatures and emission of radiation. Depending on the type of accretion, periodic or aperiodic variations of intensities are observed in different frequency bands. Accretion may cause the interstellar material to spiral into the AGNs forming a disc like structure. Dissipation of energy due to non–uniform rotation of different layers of this accretion disc may also lead to wide range of temperatures and radiation.

This is a brief account of the different processes that are taking place in the universe and their associated radiations. A detailed and more rigorous account of these processes can be found in the references below[14–17].

iii) The Space Frontier

Adaptive optics improved and refined our ground based observations in the visual range of frequencies. But a complete knowledge of the universe can only be obtained if observations are done in all possible bands of electromagnetic waves. Earth's atmosphere blocks a major portion of electromagnetic radiation (Fig.3).

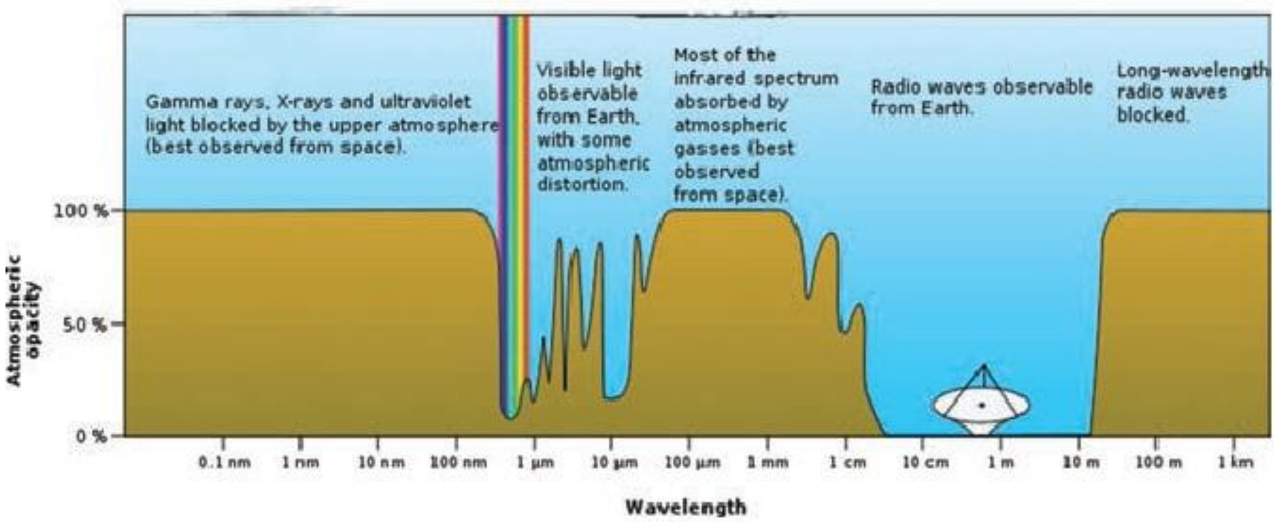

Fig.3, This illustration shows how far into the atmosphere different parts of the EM spectrum can go before being absorbed. Only portions of radio and visible light reach the surface. (Courtesy: STScI/JHU/NASA)

From the earth's surface we are able to receive only the visible(VIS) range of frequencies, radio frequencies and some extremely narrow ranges of frequencies of both the ultra–violet(UV) and infra–red(IR) bands. Such limitations in terrestrial observation heavily affect the sciences of Astronomy and Astrophysics. Perhaps this particular issue had prompted astronomer Linus Spitzer to propose the concept of a space telescope or a space observatory way back in 1942. His dream was to put in orbits around the earth, satellites fitted with telescopes working in suitable frequency bands. After a brief period of launching cameras and detectors mounted on sounding rockets and balloons the National Aeronautics and Space Administration (NASA), following Spitzer's dream launched the Uhuru X-ray observatory in 1970. Since then some milestones in the world of the Space observatories has been the Hubble Space Telescope (HST) in 1990, the Compton Gamma Ray Observatory (1991), the Chandra X-ray Observatory (CXO) in1999 and Spitzer Space Telescope 2003. A few details of these observatories have been provided in the Table–1[18–21].

Table–1: Four milestones in the era of space telescopes and observatories

Telescope/Observatory	**Year launched:**	**Telescope type:**	**Light collector:**	**Mirror diameter:**	**Light observed:**
Hubble Space Telescope	1990	Reflector	Aluminum-coated glass mirror	94.5 inches (2.4 m)	Infrared, visible, ultraviolet
Compton Gamma Ray Observatory	1991	Detector	Gamma ray counter	------	Gamma ray
Chandra	1999	Reflector	8 iridium-coated glass mirrors	Nested mirror arrangement with each mirror 32.8 inches (83.3 cm)	X-ray
Spitzer	2003	Reflector	Beryllium metal mirror	33.5 inches (85 cm)	Infrared

Since then both NASA and the European Space Agency (ESA) have launched several space telescopes (XMM Newton launched in 1999 being the landmark in the history of space observatories launched by the European Space Agency, ESA)[22–26]. Countries like Japan are not far behind with launches like the ASCA in 1993 and Suzaku in 2005. India recently launched its multi–wavelength space observatory, ASTROSAT. The details of which are discussed in the following sub–section.

iv) ASTROSAT

ASTROSAT is a multi-wavelength space observatory made out of mostly indigenous technology that was launched atop the Indian Space Research Organization work horse launch vehicle PSLV, from Satish Dhawan Space Centre, Sriharikota on **September 28, 2015.** It is basically an Indian Remote Sensing class of satellite fitted with five sophisticated instruments that will be orbiting the earth in a 650 km, near-equatorial orbit. It is expected to have an operating life time of more than five years.

ASTROSAT Instruments: A Brief Description

Fig. 4 is a diagram of ASTROSAT without the solar panels deployed. The details of the five major instruments on board in ASTROSAT namely the Ultraviolet Imaging Telescope (UVIT), the Soft X-ray Telescope (SXT), the Large Area X-ray Proportional Counter (LAXPC), the Cadmium Zinc Telluride Imager (CZTI) and the Sky Scanning Monitor (SSM) are given in Table–2[27].

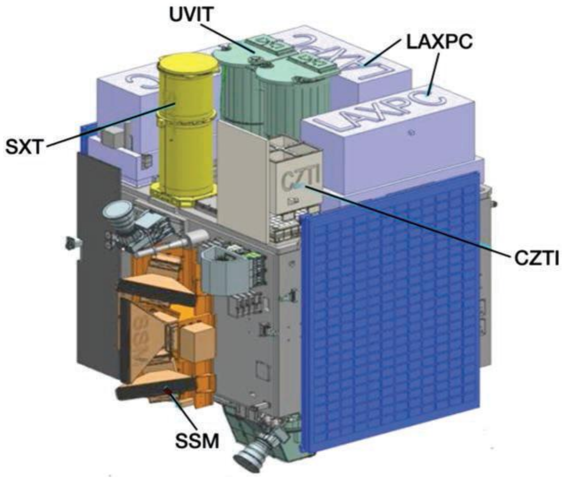

Fig. 4. The stowed view of ASTROSAT and its five instruments.

Table–2 The five instruments of ASTROSAT and their characteristics

Features	**UVIT**	**SXT**	**LAXPC**	**CZTI**	**SSM**
Detector type	Intensified CMOS, used in photon counting mode or integration mode	X-ray (MOS) CCD (at the focal plane)	Proportional counter	CdZnTe (Cadmium, Zinc and Telluride) detector array	Positionsensitive proportional counter
Used for imaging/non-imaging	Imaging	Imaging	Non–imaging	Imaging	Imaging
Optics	Twin Ritchey-Chretian 2 mirror system.	Conical foil (~Wolter-I) mirrors 2m focal length	Collimator	2- D coded mask	1-D coded mask

Bandwidth	FUV (130-180nm) NUV (200-300 nm) VIS (320-550 nm)	0.3 – 8 keV (low energy)	3 – 80 keV (medium energy)	10 – 100 keV (high energy)	2.5 – 10 keV
Effective Area (cm^2)	10 – 50 (depends on filter)	128 (1.5 keV) 22 (6 keV)	8000 (5 – 20 keV)	480 (10 – 100 keV for normal incidence)	~ 11 (2 keV) ~53 (5 keV)
Field of View (FOV)	28' dia	~ 40' dia	1° x 1°	6° x 6°	10° x 90°
Energy Resolution	<1000 A (depends on filter)	~5-6% at 1.5keV ~2.5% at 6keV	12% at 22 keV	6% at 100 keV	25% @ 6 keV
Angular Resolution	1.8 arcsec (FUV) 1.8 arcsec (NUV) 2.2 arcsec (VIS)	~2 arcmin (HPD)	~(1-5) arcmin (in scan mode only)	8 arcmin	~12 arcmin
Time Resolution	1.7 milliseconds(ms)	2.4 sec, 278 ms	10 microsec	20 microsec	1ms
Typical observation time/ target object	30 min	0.5 – 1 day	1 – 2 days	2 days	10 min

The Ultra Violet Imaging Telescope (UVIT) is a two telescope arrangement which will be used primarily as an imaging instrument in three channels, one telescope will work in the far ultraviolet (FUV), and the other in both near ultraviolet (NUV) and the visible (VIS) frequencies. Both the telescopes are of Ritchey–Chretien[27] type having hyperbolic primary and secondary mirrors. UV and VIS waves reflected from these mirrors are passed through high resolution filters that can be rotated and then they are allowed to enter photon counting detectors. The Soft X-ray Telescope (SXT) is also used for imaging. X-rays have high penetrating power and hence is very difficult to focus using ordinary mirrors. However, using highly polished mirrors and grazing angle incidence optics (when the X-rays are made incident almost parallel to the mirror surface) the X-ray waves are internally reflected. In SXT a system of conical gold foil coated X–ray reflecting mirrors using Wolter–1 (a set of paraboloid primaries and hyperboloid secondaries) focuses the X-ray waves in a CCD focal plane detector. The Large Area X-ray Proportional Counter (LAXPC) comprises of three proportional counters. An X-ray proportional counter consists of a gas filled enclosure fitted with two electrodes maintained at a potential difference. X-ray photons trigger creation of photo electrons in the gas which subsequently multiply the generation of photo electrons. A charge pulse results which is then converted to voltage, amplified and measured resulting into detection of the photon. The number of such detections determines the intensity of the X-ray source. The Cadmium Zinc Telluride Imager (CZTI) is also an X-ray imager without any elaborate reflector arrangements like the SXT. It is basically an array of pixilated solid state detectors that can detect very high energy photons like that of hard X-rays. The shadow cast by the coded aperture mask (CAM) on the pixilated detectors enables determination of the exact location of the source above the detector. The Scanning Sky Monitor's (SSM) purpose is to roughly scan a large portion of the space to look for transient behavior of X-ray sources (except the Sun) and to alert the other high precision instruments on board and terrestrial to carry out detailed observations. As is evident, most of the ASTROSAT instrument is highly sensitive to electric charge. Special measure is taken to protect these instruments from these stray charges electric charges and an instrument called the Charged Particle Monitor CPM controls the opening and closing of the instruments' protective covers when encountered by showers of stray charges like the South Atlantic Anomaly (SAA)[27].

ASTROSAT's Capabilities: The heavier the stars, the hotter they are and more likely are they to emit in higher frequencies. Particularly objects like massive young stars, white dwarves (the ones resulting from stars slightly heavier than Sun), binary star systems shine in UV. UVIT is expected to study them and their properties. Some stars like our Sun are born individually but many are born in globular clusters. The high density of stars at the centre of such globular clusters often cause merger resulting into the formation of exotic stars like the Low Mass X-ray Binaries (LMXB). These are brighter than normal stars in UV frequencies. Hence UVIT can detect these. SXT has a fair sensitivity along with very good spectral resolution and imaging capabilities (~arcmin). Galaxy clusters, Super Massive Black Holes, AGN, compact objects, stellar black holes etc are known to emit in the band of frequencies of SXT. In addition to these, the K–lines resulting from the S, Si, Ar, Ca and Fe ions, typical of hot thermal coronal plasma and the fluorescent line emissions from the photo–ionized compact objects, can also be resolved by SXT. SXT is also capable of studying low energy X-ray absorptions and thus determining the intermediate absorbing medium between the emitter and the observer. LAXPC with its good time resolution (~10 microsec) and high sensitivity due to its very large area can undertake the time variability studies of weak X-ray sources. The excellent time resolution of LAXPC will enable it to make new revelations about the periodic variations like pulsations from pulsars, Quasi Periodic Oscillations (QPOs) and aperiodic variations like outbursts like flares. LAXPC in studying Pulsar's characteristic cyclotron lines would be able to determine their magnetic fields. The hard X-ray instrument CZTI will study the X-ray binaries, pulsars, AGN etc and help in understanding the physical processes behind their continuous X-ray emissions. In addition to that CZTI can detect the cyclotron lines of Pulsars and hard X-ray emissions of objects like non–rotating neutron star or Magnestar. The most astounding feature of the CZTI is its capability to study the gamma ray photons (>100keV) energy, typical of gamma ray bursts, in a wide FOV (unrestricted by the collimator).[27–29].

3. Conclusion

The universe is pervaded with high energy phenomenon beginning from the initial explosion to the birth and death of stars. Such high energy, rapid, active processes rather than the slow evolving ones are the norms of the universe. So observing the space only in the visible frequency band provides an incomplete picture of the universe. A majority of the high energy processes mentioned above be it the supernovae, accretion of material by the compact objects or the active galaxies involve emissions of X-ray, UV waves and even higher energy photons. This is why much before the launch of the HST in 1990 to improve astronomical observations in the visible frequencies, the era of the space X-ray observatories had begun as early as 1970 with the launching of the Uhuru observatory by NASA. This was followed by the High Energy Astronomical Observatory (HEAO–1) in 1977, the HEAO–2 in 1978, EXOSAT in 1983, Rossi X-ray Timing Explorer (RXTE) in 1995 and both the Chandra X-ray Observatory (CXO) and the XMM Newton in 1999. As a result of these launches the numbers of X-ray sources which are known today are 1,100,000 in comparison to the 59 sources that were known before the launch of Uhuru in 1970. But this number is still much less than the expected 100 billion or more X-ray sources in the universe. ASTROSAT has a big role to play here. In the UV domain the most remarkable has been the findings of Galaxy Evolution Explorer (GALEX, NASA, 2008). It has not only provided the largest catalogue of the UV sources till date but has also studied the evolution of galaxies in detail. UVIT of ASTROSAT although much smaller, has a FOV 80 times that of HST. Although GALEX provides bigger FOV it has a resolution of 5 arcsec which is much coarse than UVIT's 1.8 arcsec. The world awaits some fascinating discoveries in the UV sky through the high resolution survey of UVIT. As SXT, LXPC and CZTI work in overlapping energy bands multiple features of single sources may be simultaneously revealed by them. SXT and LXPC's time resolved and frequency resolved spectroscopic capability is another unique feature of ASTROSAT; never before has any other X-ray observatory done spectroscopic studies of sources with such capabilities.

There have been space observatory missions with higher spatial and temporal resolution in individual bands of frequencies. ASTROSAT with its unique combination of scientific payloads can study the universe through photon energies beginning from the visible to the 100keV energies. Its CZTI can go even beyond. Additionally, ASTROSAT is capable of making spatial, spectral and temporal studies in all its frequency bands. These are the factors that might make ASTROSAT a game changer in the era of space observatories. ASTROSAT's data exclusively and combined with other space based and ground based observatories is well expected to provide results that might change the way we understand the origin and evolution of the universe.

References:

1. http://galileo.rice.edu/sci/instruments/telescope.html#3
2. A.V. Helden etal. (Editors), The Origins of the Telescope, Edited by: KNAW Press, Amsterdam, 1st Edition (2010).
3. http://www.stsci.edu
4. _http://amazingspace.org/resources/
5. H. W. Babcock, "The possibility of compensating atmospheric seeing", Publications of *the Astronomical Society of the Pacific*, **65**, 229–236 (1953).
6. J. H. Jeans, The Stability of a Spherical Nebula, *Phil. Trans*. R. Soc. Lond. A **199**, 1-53 (1902).
7. R. H. Fowler, M.N., **87**, 114 (1926).
8. S. Chandrasekhar, *Phil. Mag*., **11**, 592 (1931).
9. S Chandrasekhar, *An Introduction to the Study of Stellar Structure*, Dover Publications, 1st edition, 412–452 (1958).
10. T. Gold, *Nature*, **218**, 731–732 (1968).
11. T. Gold, *Nature*, **221**, 25–27, (1969).
12. F. Pacini, *Nature*, **216**, 567–568 (1967).
13. F. Pacini, *Nature*, **219**, 145–146 (1968).
14. Marc L. Kutner, *Astronomy:A Physical Perspective*, Cambridge University Press (2003);
15. J. E. Trumper and G. Hasinger (Editors), *The Universe in X-Rays*, Springer–Verlag, Berlin Heidelberg (2008);
16. Ian Morison, *A Journey Through the Universe Gresham Lectures on Astronomy*, Cambridge University Press (2015).
17. http://imagine.gsfc.nasa.gov/science/
18. http://hubblisite.org
19. http://cossc.gsfc.nasa.gov/
20. http://chandra.si.edu/
21. www.spitzer.caltech.edu/
22. http://heasarc.gsfc.nasa.gov/docs/heasarc/missions/eureca.html
23. http://www.cosmos.esa.int/web/xmm-newton
24. Martin C. Weisskopf *et al*. *The Astrophysical Journal*, 536, L81–L84, 2000;
25. T. Tamura *et al*., *Astronomy & Astrophysics* **365**, L87–L92 (2001).
26. F. Jansen *et al*., *Astronomy & Astrophysics*, **365**, L1–L6 (2001);
27. ASTROSAT Handbook ver 1.6, Indian Space research Organization;
28. www.isro.gov.in/Spacecraft/**ASTROSAT**
29. P.C Agarwal, *29th International Cosmic Ray Conference Pune* , **4**, 171–174 (2005)