Space and physical sciences

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Being a physicist, having close links with space efforts of the country, I propose to use this opportunity to share with you the excitement of doing physics the space-way. Over the last three decades, we are witnessing a phase of science research where breakthroughs or opening of new frontiers of knowledge are becoming increasingly possible only with advances in experimental techniques and technology with technological and scientific advances driving each other. Here I propose to cite some specific examples of fundamental contributions to physics made possible by advances in space technology, a more exhaustive list of which is given in Table 1. I shall also discuss the possibilities of doing experiments in physical sciences using the Indian space platform.

Contributions in high energy astrophysics

Introduction

With the advent of space exploration, new windows in the electromagnetic spectrum namely, gamma ray, X-ray, extreme UV and several regions of IR have been opened up for detailed investigation from space platforms. The birth and growth to maturity of X-ray and IR-astronomy and more recently gamma ray astronomy through satellite missions like Uhuru, Einstein observatory, ROSAT, IRAS and Compton Gamma Ray Observatory are prime examples of this development. I shall choose a few topics in X-ray astronomy, to highlight the significant results that have emerged out of the above investigations.

Observational X-ray astronomy was born with rocket-borne experiments way back in 1962 and matured with the launch of the first X-ray astronomy satellite UHURU in 1970. The observation of bright X-ray sources with luminosities ranging from 10^{36} to 10^{38} erg/s provided the opportunity to understand and investigate matter at extreme densities (10^{14} to 10^{15} g/cc) with very high surface temperatures (> million K) and very strong magnetic fields ($\sim 10^{12}$ G).

Basic understanding of the physical processes of accretion of matter by compact stars having intense gravitational potential came about from X-ray astronomy. Most of the bright X-ray sources are found to be in binary systems where one of the stars is a compact object (white dwarf, neutron star or a black hole) which accretes matter from a companion star which is more evolved than the Sun. The infalling matter acquires a large kinetic energy as it falls on to the surface of the compact object and this energy is released as radiation.

The mass loss from a supergiant companion star can be typically $\sim 10^{-5}$ $M_{\odot}$/year. Even if 0.1% of this matter gets accreted on to a neutron star, the transfer of matter, at a rate of 10^{-8} $M_{\odot}$/year, with a mass to energy conversion efficiency of 10% can give rise to luminosities of the order of 10^{38} erg/s. This is 10^5 times the total luminosity of the sun and is 10^9 times the X-ray luminosity of the sun. Such high energy liberated around a small-sized object like a neutron star can only be carried away by high energy photons and thus these objects appear as bright X-ray sources.

I shall now discuss two cases where X-ray observations from space have enabled us to make one of the first measurements of the mass of a neutron star and the first identification of a candidate black hole.

Determination of the mass of a neutron star

The object I choose for this purpose is Her X-1 which is the brightest X-ray source in the constellation of Hercules. Discovered by the Uhuru satellite, it exhibits short timescale pulses with a period of about 1.24 seconds both in the X-ray and optical wavelengths, attributed to the rotation of the compact object. The pulsations are caused by the accretion of matter on to the magnetic poles of the compact object, whose magnetic axis is tilted with respect to its rotation axis.

The Doppler shift observed in the 1.24 second X-ray pulsations provides the radial velocity curve of the binary system and this curve being sinusoidal, indicates

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Table 1. Relevance of space platforms to physics

Feature provided by space platforms	Subject benefited	Topics of special interest
New EM radiation windows	Astrophysics	Extremely high energy generation mechanisms Extremely compact objects Missing mass Cosmic background radiation
In situ measurements	Atmospheric physics	Physical, chemical and radiative relationships in the atmosphere/ionosphere Instabilities in low density plasma
	Magnetospheric physics	Transport of charged particles trapped in magnetic field and violation of adiabatic invariants Solar wind geomagnetic field interaction
	Fundamental physics	Tests of general relativity Constancy of G and c
Unattenuated particle radiation	Cosmic ray physics	Anomalous component and heavy ions in cosmic rays
Microgravity ($\sim 10^{-6}$ g) and ultra-high vacuum ($\sim 10^{-8}$ Torr)	Materials science	Marangoni convection Interfacial phenomena Phase separation and critical points in fluids Diffusion Adhesion Crystal growth Physical metallurgy
Approachability of planetary bodies	Planetary physics	Evolution of planetary surfaces
Earth images	Meteorology and oceanography	Mesoscale phenomena

that the orbit is nearly circular. The amplitude of this curve in terms of the time delay of these pulses (Δt), as the X-ray source approaches and recedes from us, gives the projected radius $R \sin i$ of the orbit

$$R \sin i = c^* \Delta t = 3.9*10^{11} \text{ cm} = 5.6\ R_{\odot}, \quad (1)$$

where i is the inclination of the orbital plane with respect to the line of sight.

The X-ray star is also eclipsed every 1.7 day by the companion star. This is the binary period of the system T. Knowing the projected radius and the binary period of the system and using Kepler's laws one can determine the mass function of the system using the equation

$$\frac{M^3 \sin^3 i}{(M+M_c)^2} = \frac{4\Pi^2 R^3 \sin^3 i}{GT^2} \quad (2)$$

$$= 1.69*10^{33} \text{ g} = 0.85\ M_{\odot}$$

where M_c is the mass of the compact object and M is the mass of the companion star.

Further, with the identification of the companion star in the optical band, and using spectroscopic and photometric observations in the optical and X-ray band, estimates of M and i can be made. This leads to the determination of the mass of the compact object to be 1.1 $M_{\odot}$. Certain cyclotron features seen in the X-ray spectrum indicate a surface magnetic field of the compact object to be 10^{12} G. The mass of the object and its magnetic field coupled with its short 1.24 s rotation period and the secular variation of this period over long time scales led to the confirmation that this compact object is a neutron star. The above considerations, thus, led to the first ever observational estimate of the mass of a neutron star.

Candidate for a black hole

Applying somewhat similar analytical approach to X-ray emissions observed from the compact object in Cyg X-1 and optical observations of its companion, the mass of the compact object was deduced to be of the order of 6 $M_{\odot}$. This mass value, being twice the permissible maximum mass limit for a neutron star implied that Cyg X-1 is a black-hole. This turned out to be the first observational evidence of the existence of a black-hole.

Cosmic microwave background

Moving from the X ray wavelength, I now wish to take up a subject of contemporary interest and which has wide implications to cosmology and our understanding of physical processes leading to the early evolution of the universe.

The Cosmic Background Explorer (COBE) satellite launched last year has made extremely significant contributions to our understanding of the cosmic microwave background (CMB). In order to appreciate the significance of these new results it is relevant to provide some explanation of CMB.

CMB was discovered serendipitously by Arno Penzias and Robert Wilson in 1965 while looking for extra-solar microwave sources at 7.35 cm wavelength. Their data showed a diffuse unresolved background radiation isotropic within measurement limits. Such a cosmic background radiation was indeed predicted by George Gamow in 1949 as one of the three evidences of his Big Bang cosmological model, the other two evidences being the Hubble expansion and the He/D abundance. Three characteristics of the observed CMB attributed its cosmological origin. Its black body spectrum with a temperature very close to 2.7 K, its extreme isotropy (besides the dipole component observable due to the motion of earth relative to the general expansionary motion of the universe) and the fact that clusters of galaxies have been observed between its source and the observer through the detection of the so-called Sunyaev–Zeldovich effect. Sunyaev and Zeldovich had pointed out that if hot intergalactic gas is the dominant contributor to the X-ray emission from clusters of galaxies, it would also produce a measurable local distortion of the CMB spectrum, since intercluster hot gas electrons would scatter cosmic background photons passing through the cluster modifying their energy distribution. Thus the spectrum of CMB would appear distorted in the direction of a cluster and unaltered on its side.

The origin of CMB and its observed black body temperature of 2.7 K are well understood in the frame of the Big Bang model as the relic of the cosmic radiation present in the period when matter-radiation decoupling took place. Although the observed CMB is highly isotropic, the various theories of galaxy formation have predicted small scale anisotropies (after correcting for dipole component and the Sunyaev–Zeldovich effect) in the total radiation energy density of CMB amounting to fluctuations of the black body temperature, $\Delta T/T$ of the order of 10^{-4} to 10^{-6} at spatial scales of a few arcminutes, depending on the particular feature of the galaxy formation theory.

To put in simple words, this arises from the fact that the existence of large scale structure in the matter of the universe observable at present in the form of galaxies, galactic–clusters, super-clusters, etc. can be explained only if density fluctuations of the order of 10^{-4} are presumed to be present in the universal matter at the time of decoupling. If these density fluctuations took place at the time of decoupling adiabatically the temperature then should also have fluctuations $\Delta T/T$ of roughly the same order. Since cosmic radiation has been preserved after scattering from such a matter at the time of decoupling, this temperature fluctuation $\Delta T/T$ should show itself an anisotropy of roughly the same order in CMB received today.

In a baryonic universe density fluctuations could originate only when baryons combined to form atomic matter at the time of decoupling. The anisotropy in CMB in that case should be of the order of 10^{-4} at a spatial scale of a few arcminutes. But if the matter in the universe has non-baryonic content (in the form of weakly interactive massive particles), according to some theories, quantum-mechanical fluctuations can give rise to gravitational fluctuations much before the decoupling event. At that time ($\sim 10^{-34}$ s after the Big Bang) the existence of fluctuations of the order of 10^{-6} would suffice to explain the present structures. CMB observable now in this case should exhibit anisotropy at a finer scale, viz. of the order of 10^{-5} to 10^{-6}.

Many attempts were made to measure this anisotropy at various scales and wavelengths using ground-based observations, but the first positive detection of anisotropy became possible only on analysis of the observational data collected by the COBE satellite from outside the Earth's atmosphere. COBE has provided so far the following results.

(i) CMB spectrum indeed fits ideally to a black body radiating at 2.735 ± 0.06 K and there is no excess radiation at any wavelength. This spectacular result came from just 9 minutes of observation near the galactic north pole.
(ii) Best estimated value of dipole anisotropy of CMB which gives $v/c = 0.00122 \pm 0.0006$ corresponding to a speed of 365 ± 18 km s^{-1} of the earth in the direction $l = 284.7° \pm 0.8°$, $b = 48.2° \pm 0.5°$ in relation to the general expansionary motion of the universe.
(iii) Anisotropy in CMB in terms of root mean square fluctuation in temperature is $(\Delta T/T)_{rms} = (1.1 \pm 0.2)10^{-5}$; the quadrupole contribution to this anisotropy is $(4.8 \pm 1.5)10^{-6}$. These values may rule out baryonic theories of galaxy formation and favour non-baryonic theories.

The above results are based on analysis of COBE data gathered during the first year of its operation. The second and third year data are under analysis.

Experimental tests of relativity and gravitation

The above examples of application of satellite to basic physics used the capability of these platforms to provide

Table 2. Tests of relativity using space platforms

Property under test	Related numerical quantity	Space technique	Limits provided accuracy achievable
Temporal and spatial constancy of Newton's gravitational constant, G	Smallness of $\eta_\infty = \mid \{G(r) - G_\infty\}/G_\infty \mid$ G is G at solar system distance or more	Radar and laser ranging measurements by Viking to Mars in 1982 and a few other missions	$\mid \dot{G}/G \mid < 10^{-11}$ per year which is appreciably smaller than the present Hubble constant
Time delay of light in the vicinity of a massive object (Sun)	Relativistic delay in round-trip travel time for a radar signal sent from one point in solar system to the other is $\Delta t = \frac{rs_\odot}{c}(1+\gamma)\ln 4\frac{d_\oplus dp}{d^2}$ $d_\oplus$ = distance from source to sun dp = distance from reflecting point d = shortest distance from signal path to sun	Radar signal set to earth from spacecraft around Mercury, Mars and Venus $r_{s\odot}$ = Schwarzschild radius and γ = PPN, the parameter to be determined	$1/2(1 + \gamma) = 1 \pm 0\ 001$ by Viking-Lander Mars data
Deflection of light by massive objects (Sun)	Deflection angle $\Delta\varphi = (1 + \gamma)r_{s_\odot}/d$ where γ is again the same PPN parameter which measures the curvature of space and d is minimum distance to light ray path	Astrometry of stars near the solar limb using Hubble Space Telescope & HIPPARCOS	HST observations are expected to improve the positioning accuracy by an order of magnitude, HIPPARCOS to 2×10^{-3} arcsec. and the proposed spaceborne optical interferometers to 10^{-6} arcsec
Dragging of local inertial frame in the vicinity of a rotating massive object (Lens – Thirring effect)	Angular velocity of drag of frame of reference $\Omega_{LT} = GL/2c^2r^3$ L = angular momentum of rotating object	Detecting precession of axis of satellite borne gyroscopes (aligned with respect to distant star) under the influence of rotating earth (Expected value = 0 05 arcsec per year)	Precession of axis can be measured to an accuracy of 5×10^{-4} arcsec, which implies detection of LT effect at 1% level
Relativistic precession of orbits around sun	Solar quadrupole moment J_2 which governs the accuracy of precession	Placing STARPROBE satellite in a highly eccentric orbit of period around 4 to 5 years but perihelion dis about $4r_\odot$ and measuring a number of properties.	J_2 measurements possible at 10^{-8} level, gravitational redshifts at 10^{-9} level

access to new regions of EM spectra. I will now like to draw your attention to a good example where the capability of satellites to reach various points in space is innovatively exploited to measure some basic physical parameters. These relate to detection of relativistic effects in solar system.

Introduction

Apart from observations of perihelion shift of Mercury's orbit, accurate observations of periodicities of pulsars at radio wavelengths have provided some proofs of the concepts of general relativity, including variation of mass of an object at large relativistic speeds, the bending of light rays, the Shapiro time delay and intense gravitational radiation emitting from binary system.

In Table 2, a summary of improved measurements from space relating to the predictions from theories of relativity and gravitation is given. To give an idea of the capability of space platforms for this class of physics experiments, I would now elaborate the details of the proposed experiment to measure one of the relativistic effects in solar system, namely the Lens-Thirring effect.

Measuring Lens-Thirring effect using dual-gyroscopes

In 1918 Lens and Thirring derived from general relativity that the rotation of a massive body influences the space-time outside. An observer at a distance r should experience the dragging of his/her local inertial frame with an angular velocity

$$\Omega_{LT} = GL/2c^3r^2, \tag{3}$$

where L is the angular momentum of the rotating body. This implies that test gyroscopes fixed with respect to

Table 3. LT precession in arcseconds per century for different rotating objects

Rotating object	Precession measurement site	Expected precession rate
Sun	$4\,r_{o}$	20
Sun	Mercury	0 002
Saturn	Mimas	20
Earth	10^4 km orbit	4
5 ton sphere rotating at 1000 Hz	Distance of 1 km	10^{-6}

inertial frame of a distant star would precess if placed in vicinity of a massive rotating object.

The Lens-Thirring effect is very small as is shown in Table 3.

It is evident from Table 3 that measurement of LT effect in laboratory is very difficult using existing technologies. An orbital platform around earth provides an effective alternative. Considering this, the Stanford University is preparing for a satellite experiment in which two superconducting gyroscopes will be flown on a drag-compensated satellite in a 1000 km polar orbit. Spin axis of one of the two gyroscopes in this experiment will be aligned in a direction parallel to the orbital plane to measure the 'geodetic' precession, which is expected to be around 6.9 arcsec per year. The second gyroscope with its axis normal to the orbital plane will enable detection and measurement of the superfine LT effect to an accuracy of 1%. It may be noted that LT effect has so far not been measured.

It is proposed to flight test the components of this experiment on a Space Shuttle mission in the near future. If this is successful operational flight could follow within a few years.

Physical phenomena under microgravity

Introduction

Let us now touch upon another class of basic physics experiments where the emphasis is to make use of the microgravity environment provided by orbital platforms. Microgravity research is a newcomer among physical sciences and perhaps still not well known among physicists not directly involved in it. When an object is in a state of free fall in a gravitational force field, it is under weightless condition. This condition can be approximately simulated in a number of ways such as (i) a drop-tower or drop-tube where experiments are carried out on minute samples of liquid or melts while they are undergoing free fall of several seconds duration, (ii) in rocket flights which can provide a few minutes of near weightlessness ($\sim 10^{-4}$ g) after rocket fuel has fully burnt off and payload has been despun, (iii) in an aircraft following a parabolic trajectory (Keplerian projectile motion), and (iv) in an orbiting satellite which can provide longest duration of microgravity. It may be recalled that an object in a circular orbit around a massive gravitating object is in a condition of continuous free fall since the force of gravity GMm/r^2 is balanced by the centrifugal force mv^2/r. The orbital velocity derived from the equality of above two forces, $v = (GM/r)^{1/2}$ is indeed independent of the mass of the orbiting object. Hence as for object in a free falling lift, inside a satellite all objects would move at the same velocity.

In practice, however, absolute weightlessness is impossible to achieve as a number of secondary effects disturb the environment. Among these sources of disturbance are (i) tidal acceleration, (ii) drag due to residual atmosphere at orbital heights, (iii) radiation pressure, (iv) effects of mechanical movements and thrusts generated artificially as part of satellite in orbit operations. The term microgravity is derived from the order of magnitude of the sum of accelerations due to disturbances (i), (ii) and (iii) which add up to a millionth of Earth's gravity. The residual acceleration generated due to (iv) are referred to as *g*-jitter and depending on the inorbit operation (including satellite spin and also astronauts' activities) the *g*-jitter can be between 10^{-4} and 10^{-6} g.

In a microgravity environment it is possible to do basic physics research for the following reasons:

(i) Near absence of gravitational force makes it feasible to observe at larger scale certain static and dynamic effects of intermolecular forces and motions which are otherwise suppressed under the 1-g environment on ground. Among these are phenomena related to diffusion, capillarity, interfaces, critical point phenomena in fluids and convection driven by forces other than buoyancy. (Marangoni convection is an example of one such convection phenomenon which is easily seen in space experiments employing liquids. This is driven by surface tension gradients caused across the free surface of liquid because of changes in temperature or solutal concentration.)

(ii) Gravity-induced density gradients, convection and mechanical stresses are sources of disturbance in achieving quality of end products in several material processing routes. (Growth of crystals, float zone refining, directional solidification, electrophoresis, etc.) Apart from achieving, in principle, better quality end product, it is also possible in the microgravity environment of an orbiting platform to do fundamental research into the basic phenomena involved in deposition of material on a growing solid surface, nucleation in undercooled melts, metastable alloys, quasi-crystalline material, etc.

I shall now describe briefly two categories of experiments dealing with fundamental physics where the measurements can be carried out with much higher precision only in the microgravity environment.

Diffusion and atomic transport phenomena

Diffusion and atomic transport processes play an important role in the production of all kinds of materials. Precise values of atomic diffusion coefficients are needed for various rates of growth calculations. Unfortunately, it has always been a difficult task to measure accurately these processes or their temperature dependence because convection driven by gravity and other forces disturb or enhance the atomic transport by diffusion.

The measured effective diffusion can have contributions due to various factors.

$$D_{\text{eff}} = D_{\text{at}} + D_{\text{wall}} + D_{\text{M}} + D_{\text{g}} + D_{\text{em}} \tag{4}$$

where D_{at} is the required atomic diffusion coefficient, D_{wall} the contribution from wall effect, D_{M}, D_{g}, D_{em} from Marangoni, gravity (residual) driven and electromagnetic convections respectively. By choosing suitable sample geometry and taking certain precautions it is possible to reduce D_{M}, D_{g} and D_{em} in a space experiment to nearly zero and hence the condition can be approximated to

$$D_{\text{eff}} = D_{\text{at}} + D_{\text{wall}}. \tag{5}$$

Here D_{wall} can also be corrected for by measurements at different capillary diameters. Hence space experiments have been recognized as the ideal tool to determine the real atomic diffusion coefficients in liquids.

Figure 1 shows results of a typical D measurement in space shuttle microgravity experiments. For comparison best results from ground experiments for the same system (Sn) are also plotted. Three features of D measurements in microgravity that can be easily noted in relation to the ground measurements are (i) a uniformly lower value of D at all temperatures, (ii) almost complete absence of scatter in data and (iii) a clearly delineable temperature dependence. Analysis of space data shows that the temperature dependence of D is best represented by a relation $D = KT^2$. This conforms to Swalin's fluctuation model of atomic diffusion and clearly violates the Arrhenius Law presumed applicable in atomic transport rate calculations. It remains to be seen with the help of future space experiments, whether this violation of Arrhenius Law is a universal fact or is true only in the case of diffusion in Sn systems.

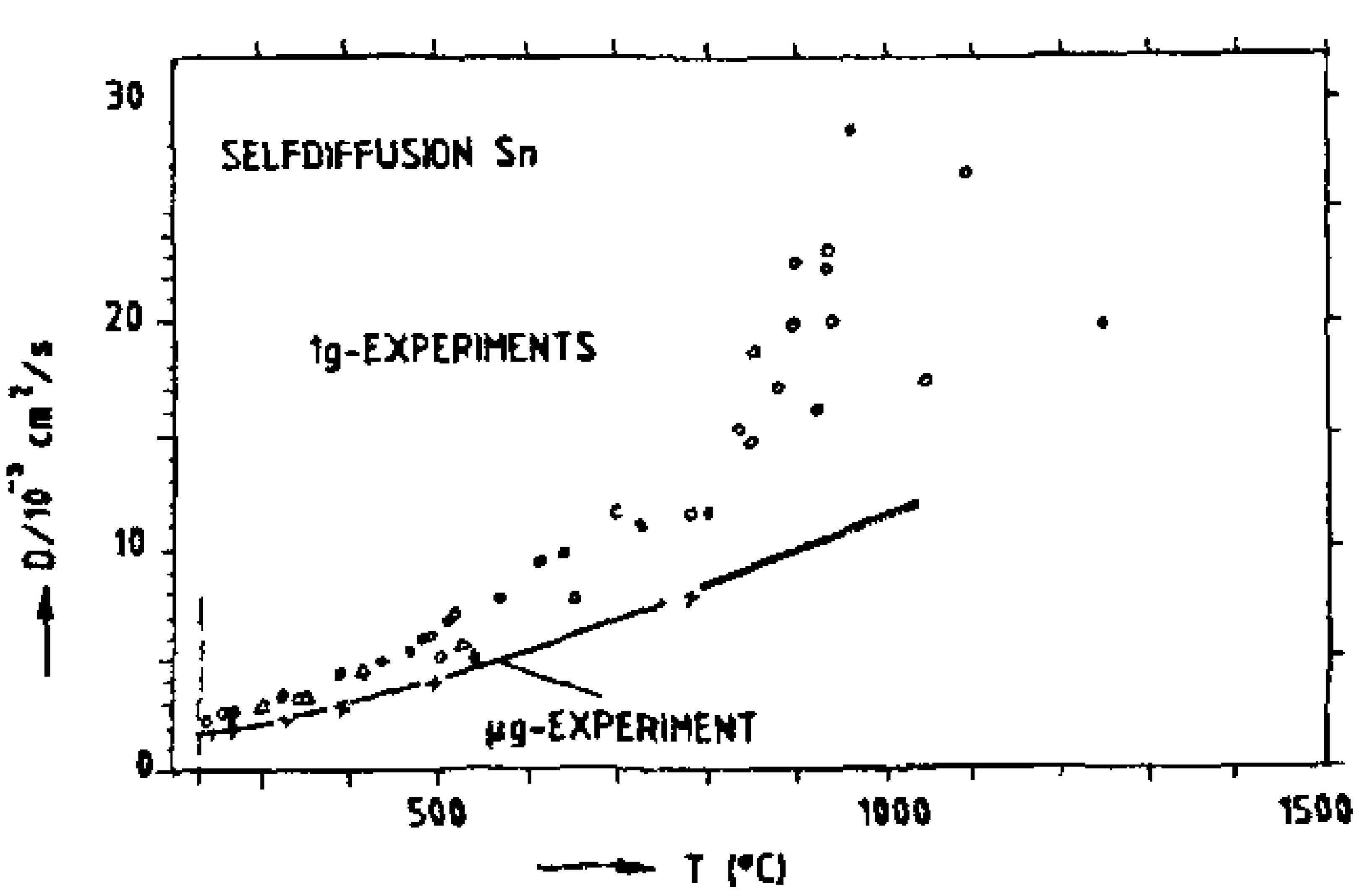

Figure 1. Best diffusion measurement results from ground compared with µg results (figure derived from Frohberg, G *et al.*, ESA SP-256 Feb. 1987).

Ultra-cold atomic collisions

Another experiment that I have chosen deals with one of the most interesting areas of contemporary physical research, namely investigations on atoms and ions in conditions of controlled density, position and velocity. Using the laser-cooling technique it is possible to slow-down vapourized atoms to kinetic energy levels equivalent to temperatures of microKelvin or less and then further localize them temporarily in small regions of a few cubic mm using magnetic traps. Congregation of such low velocity trapped atoms is referred to as atomic molasses. Under the conditions of ultracold very-low velocity collisions in such atomic molasses the atom–atom and atom–surface interactions are expected to exhibit exotic routes because of several reasons: (i) the de-Broglie wavelength becomes orders of magnitude longer than the range of chemical binding force; (ii) the Maxwell-Boltzmann distribution assumes a width comparable with the natural width of atomic transitions; (iii) collision times become long compared with the radiative lifetimes; and (iv) weak, long-range interactions control the probability of inelastic events. In experiments on ground, the observation time of such interaction is considerably reduced because the slowed atoms fall out of the observational region due to gravity. Under microgravity environment of an orbiting satellite much longer observation times are possible enabling detailed investigations.

A group of Italian scientists from MARS, and Universities of Florence and Naples have proposed to perform such an experiment onboard shuttle. The idea of the experiment is a simple one. In a vapour chamber cooled to a few tens of Kelvin temperature, the atomic molasses is generated by making three polarized stationary laser waves intersect orthogonally at one point, provided the three laser waves are derived from a single laser source whose frequency is slightly detuned from the resonance frequency of vapour atoms. The atoms trapped in molasses at the intersection can then be further slowed down to nanoKelvin temperature by application of a magnetic field gradient of the order of typically 10–20 G/cc. When vapour density in the chamber is adjusted to be higher than $10^{10}-10^{11}$ atoms/cc, the molasses becomes optically thick. It can then be observed by another laser beam used as a probe. The temporal evolution of various atomic/ion species in the molasses under the effect of ultra-low velocity collisions can be observed by exciting the transitions of the relevant species using this probe laser beam and detecting fluorescent light and its variation over the sample volume from time to time using a CCD camera.

For the first experiment the proposers have chosen Cs atoms and AlGaAs semiconductor diode lasers. The reason is that resonance line of Cs atoms (at 850 nm) and transitions from the singlet and triplet ground state of the Cs_2 molecule (at 760 nm and 710 nm) can be excited using semiconductor diode lasers. Principal collisional processes that normally take place in alkali atom molasses are (i) radiative association, $A + A + h\nu_1 \rightarrow A_2^* \rightarrow A_2 + h\nu_2$, (ii) associative radiation $A^* + A^* \rightarrow A_{2+e}^+$ and (iii) spin-flips and thermalization process.

Physicists can look forward to some interesting results from this microgravity experiment when performed within a few years.

Indian satellite-borne scientific experiments

So far, I have tried to bring to your attention the diversity of approaches adopted to use space platforms to push the frontiers of fundamental physics. My efforts will remain incomplete if we do not examine what is it that we can do in the country with indigenous space capability developed over last two decades by ISRO. The capability to build and operate state-of-art satellites to meet a variety of applications has already been established. For reasons of resource constraints, it is certainly not possible at present, however, for the country to launch very major initiatives in spaceborne science. But, that does not foreclose our options. With large turn around time needed for executing scientific experiments onboard large size platforms (typical 7 to 10 years for Spacelab from the time experiment is conceptualized to the time PI gets access to the data from his experiment) and huge costs involved, the scientific community world over has turned its attention to exploiting small satellites. This issue is receiving increasing attention in many international forums of space scientists and technologists. Indian experience in building and using small satellites (inexpensive by international standards) for science has been considered extremely noteworthy in such forums. It is in view of this that I feel it is important to describe some typical Indian experiments. I hope that this will enthuse some more physics groups in the country to take interest and come up with fresh ideas for innovative experiments using Indian space capability.

A short resume of astronomy and aeronomy related satellite-borne experiments carried out or planned by Indian scientists is given in Table 4. Three types of space platforms have been developed by ISRO for space missions; a small 150 kg class SROSS satellite bus for low earth orbital missions, a medium size 1 ton class IRS satellite bus for sunsynchronous polar orbits and a 2 ton class INSAT-2 satellite for geosynchronous orbits. Capabilities and features of these three are summarized in Table 5. Three launch vehicles, viz. Augmented Satellite Launch Vehicle (ASLV), Polar Satellite Launch Vehicle (PSLV), and Geosynchronous Satellite Launch Vehicle (GSLV) are being developed by ISRO for launching the three class of satellites respectively. The INSAT-2 platform has so far not been offered for any scientific experiments. Three satellites, namely SROSS-1, SROSS-2 and SROSS-C have been conceived around the SROSS satellite bus. All the three satellites carried gamma ray burst experiment. SROSS-C carried in addition a retarded potential analyser for *in situ* measurement of some ionospheric parameters. SROSS-C2 satellite to be launched in near future is carrying the same combination of payload as SROSS-C. The proposed Polarsat-P3 mission carrying an X-ray astronomy experiment and other payloads, is configured around the IRS bus. I will now describe some details of the gamma ray burst detector experiment flown last year on SROSS-C, the X-ray astronomy experiment planned onboard Polarsat-P3 and two futuristic missions as illustrations of the capability of Indian space platforms for scientific investigations.

Gamma ray burst experiment on SROSS-C

The Gamma Ray Burst (GRB) experiment onboard the SROSS-C satellite flown in 1992 was designed to detect celestial gamma ray bursts over the energy range of 20 keV to 1 MeV with the best temporal resolution of 2 ms around the peak of the burst. Data could also be stored 65 second prior to the burst in order to detect any precursors. Spectral evolution of the burst could also be studied using spectra recorded every 1/2 second for a duration of 16 seconds. This payload detected 8 candidate events which have the characteristics of gamma ray bursts. Of these, the event of orbit 640 on 29 June 1992 is worth mentioning here because of the unique pulsations of 237 ms which were seen in this event. This period is very close to that observed in the Geminga pulsar. However, the pulsar was not in the FOV of the detector. Two other radio pulsars, PSR 1922 + 20 and PSR 1719-37 hitherto not identified as gamma ray sources but having period close to 237 ms were in the FOV. The alternative explanation could be the mirroring of precipitated electrons along the

Table 4. Indian experiments using satellites

Satellite/yr	Experiment/payload	Results
Aryabhatta 1975	CsI crystal detector with anti coincidence shield to detect high energy neutrons (10–500 MeV) and gamma-rays (0 2–20 MeV) from Sun (TIFR)	Premature termination of experiment enabled only the evaluation of neutron background rates
	Proportional and scintillation counter telescopes to detect and measure celestial X-rays in the range (2.5 to 155 keV)	Cyg X-1 was sighted and spectrum measured just before a major upward transition in the source; X-ray spectrum of two galactic centre sources measured
	Retarted Potential Analyser (RPA) to measure supra-thermal electrons in earth's atmosphere (PRL)	
	Two UV ion chambers to measure intensity of scattered Lyman alpha and excited OI (1304A) emissions (PRL)	
Bhaskara-I 1979	Wide FOV proportional counter for X-ray transient monitoring (ISAC)	Routine X-ray observations carried out for one month
ANURADHA onboard Spacelab-3 1985	Plastic nuclear track detector stacks to measure ionization states and energy distribution of anomalous and galatic cosmic-rays (TIFR/ISAC)	Several new findings on composition of heavy ions (O to Fe) – Partially ionized GCR heavy ions observed for the first time
SROSS-I & 2 1987 & 1988	Both carried gamma ray burst detectors (ISAC)	Mission failure
SROSS-C 1992	Gamma-ray burst detector (ISAC)	A few candidate GRB events recorded One of these that occurred on June 29 is unique in that it showed damped oscillation with a period of 237 ms
	Retarted potential analyser (NPL)	Ion-density profiles for several days and nights.
SROSS-C2	Same as above	
Polarsat-P3	Four large area collimated A/Xe filled proportional counters operating in pointed-mode	Time variability and spectral characteristics of cosmic X-ray sources
	Monitor proportional counters (TIFR/ISAC)	See the text for detailed scientific objectives
Indo-Russian gamma ray astronomy programme	Gamma ray telescope (Partly fabricated at TIFR)	Study of gamma-ray emissions from (i) quiet time Sun and solar flares, (ii) galactic sources and (iii) extragalactic sources simultaneously in low (0.02 to 0.2 MeV) and medium (10–100 MeV) energy range

Table 5. Capabilities and features of Indian space platforms

Parameter	SROSS Spinner	SROSS 3 axis stabilized	IRS	INSAT-2
Payload mass	35 kg	18 kg	320 kg	220 kg
Payload mounting area	260 mm hexagon	260 mm hexagon	1500 × 1000 mm^2	1700 × 1900 mm^2
Payload nominal height	350 mm	350 mm	1000 mm	Vehicle dependent
Pointing accuracy	± 1° Spin rate 3–10 rpm	Pitch ± 0.4° Roll ± 0.4° Yaw 1 to 2.5°	Pitch ± 0.4° Roll ± 0 4° Yaw ± 0.5°	Pitch ± 0 2° Roll ± 0.2° Yaw ± 0 4°
Power	Continuous 10 W Peak 100 W	Continuous 2 W Peak 100 W	Continuous 30 W Peak 840 W	Regulated 600 W
Total spacecraft mass (typical)	150 kg	150 kg	900 kg	1860 kg
Orbit	450 ± 50 km Circular with 45 ± 0.5° inclination	Same as SROSS spinner	Polar sunsynchronous	Geosynchronous
Life (nominal)	1 year	1 year	3 years	7 years

magnetic field lines since the event occurred at a high latitude.

Polarsat-P3

An X-ray astronomy experiment is proposed to be incorporated into the satellite Polarsat-P3 to be launched on one of the development flights of PSLV mission. It will be dedicated primarily to the study of time variability and spectral characteristics of cosmic X-ray sources. The experiment aims to carry out pointed mode observations of periodic and aperiodic intensity variations of galactic X-ray sources to discover pulsations, binary nature and quasi-periodic oscillations; search for short and long term variability in selected classes of extragalactic objects like Seyfert galaxies and BL Lac sources which have active and compact nuclei; and study of light curves and spectral evolution of transient and flaring X-ray sources. For this purpose the satellite will carry onboard four collimated Argon/Xenon filled proportional counters each having an effective area of about 400 cm^2 and an operational energy range from 2 to 20 keV. In order to monitor the sky for studying transient sources and flaring phenomena, it will also carry a suitable wide field monitor proportional counter system operating in the energy range 2–10 keV.

It is estimated that about 50 X-ray binaries and pulsars with a source strength of 4 UFU (one Uhuru Flux Unit = 2.4×10^{-11} erg cm^2 s^{-1}) can be detected by the counters. Another important expected contribution of this experiment will be the search and determination of binary and pulse periods in several weak (4–10 UFU) X-ray sources for which detailed X-ray studies have not yet been performed. Further, the experiment is also expected to provide detailed temporal and spectral studies of any new transients that may be discovered by the monitor counters. The proposed configuration of the satellite is shown in Figure 2.

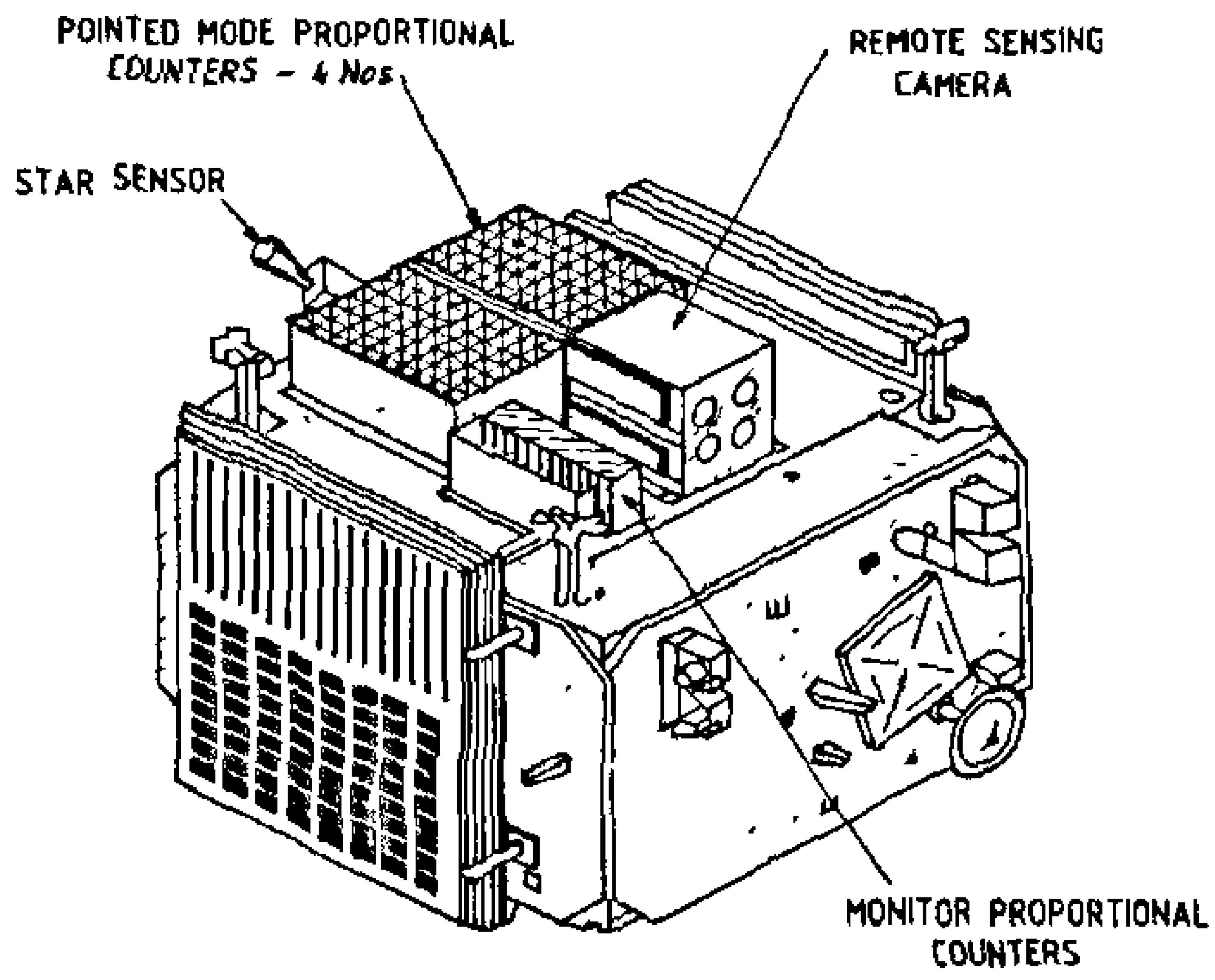

Figure 2. Proposed configuration of POLARSAT-P3

Proposed Indian multiwavelength space observatory

A space astronomy mission capitalizing on simultaneous multiple wavelength observations of celestial 'flash'/transient events has the potential to harvest new discoveries related to high energy transient phenomena in the universe. Coordinated multiwavelength observations using space-based and ground-based observatories, although recognized as very crucial to the understanding of many astrophysical phenomena, have been extremely rare due to the complexities arising from arranging such campaigns involving many countries, institutions and individuals. The need for a single satellite mission for simultaneous observations covering large frequency bands is therefore obvious. Such a satellite can enable study of temporal characteristics of short duration (~ seconds) and relatively long duration (~ weeks to months) celestial transient phenomena simultaneously in several wavelength bands of the electromagnetic spectrum. Coming under the first category are gamma ray bursters and their X-ray and optical counterparts producing X-ray and optical bursts, and X-ray bursters and optical bursts from them, and flaring objects of various types. Under the second category, we have cataclysmic variables, flare stars, RS CVn systems and the nuclei of several types of active galaxies. Further, detailed simultaneous photometric and/or spectroscopic investigations of selected targets in X-ray, UV and/or optical bands are also feasible. The proposed instrumentation for this multiwavelength space observatory will consist of several telescopes (cameras) operating in the gamma ray, X-ray, UV and optical bands. The telescopes will have large FOV, reasonable angular resolution, high speed (i.e. short integration times for temporal data collection) and reasonable sensitivity. The gamma-ray, X-ray and optical telescopes having large FOV will be complemented by a relatively more sensitive, narrow FOV optical/UV telescope which will have the capability to rapidly move on to the transient object and make detailed photometric and spectroscopic investigations in the optical/UV band.

A possible Indian interplanetary mission

The development programme of India's satellite launch vehicles, particularly the recent advances made in the realization of a geosynchronous launch capability (GSLV), has led to a few studies to explore the possibility to conceive an Indian planetary mission by the turn of the century. The results of such analysis are quite encouraging and it appears feasible to use GSLV for a mission to Mercury either as a fly-by or as an orbiter to the planet using the gravity assist trajectories of the planetary probe due to Venus and Mercury itself. The results of the study show that Mercury itself could be used through multiple swing-bys prior to orbit insertion. GSLV could launch the spacecraft first into a 300 km orbit later boosted to heliocentric orbit. While fly-by on Venus and Mercury would provide some opportunity to have a short glimpse of these planets, the Mercury orbiter could carry a number of instruments for imaging the surface and for remote measurements of the surface parameters and environment of the planet. *In situ* particle detectors, plasma probes and magnetometer onboard the orbiter could provide vital information on solar wind and associated phenomena. The instruments carried in such an orbiter could include UV spectrometer for determining elemental composition of rare and other gases (particularly to throw light on the sodium enigma of the planet), plasma analyser to measure solar wind particles in the transitional atmosphere of the planet, imaging with television or CCD cameras at a high resolution of 50–100 m in different visible and IR bands (only about half of the planet's surface has been photographed by Mariner-10), gamma ray, X-ray and IR spectroscopy to study the composition of the surface material of the planet, IR and microwave radiometers to measure thermal emissions from the planet and magnetometer for mapping the magnetosphere of the planet which may have arisen due to the internal dynamo field. A time schedule for such a mission has not been fixed as yet.

Concluding remarks

Here I have provided only a few glimpses of applications of satellite platforms to investigate problems in physics. The total scope is quite large. I have not touched at all applications to life sciences and planetary geology where again extensive efforts have been put in by many space agencies. Considering the wide range of scientific interests and expertise available among various institutions in the country, the small satellite bus-like SROSS and the medium size IRS satellite bus available indigenously hold a great potential. In a few experiments that have been carried out by Indian scientists so far only a handful of institutions have participated. It is necessary to encourage others. Bright ideas and experimental innovations can lead to conceptualization of experiments that could be carried out using the Indian space capabilities resulting in research efforts in frontiers of science.

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