it was only because of the experience gained with the complex scientific projects that the applications satellites could be built. Apart, therefore, from making a valuable contribution in its own right, the science programme also provides the technological basis from which applications programmes can evolve.

The scientific programme of ESA will also contribute to a better understanding in other fields of science and technology. An example is the interdisciplinary research which relates space science and energy studies. The greatest bar to achieving controlled nuclear fusion is the confinement of a hot plasma for a sufficiently long time, a feat which has not so far been managed in the laboratory. Nature, however, does this job on a grand scale : the magnetosphere around the earth is an almost perfect magnetic bottle, to which spacecraft give access. It can safely be assumed that space missions to be flown within the next few years, such as the Geos and ISEE projects, will further enhance the cross-fertilisation between earth-bound plasma research and space research. Active plasma experiments in space, as foreseen for early Spacelab missions, will also make a contribution.

Even if the means for carrying out space research in Western Europe have in the past been modest as compared with other space agencies, the success of all the satellites has been gratifying. ESRO/ESA has put eight scientific spacecraft into orbit, and has obtained from them scientific results that compare favourably with those of any other space agency. These results would never have been achieved without the enthusiasm and competence of the approx. 30 institutes which have supplied, sometimes under very difficult circumstances, experiments of outstanding quality to the Agency. It should also not be forgotten that national agencies have themselves flown many highly successful spacecraft and large numbers of experiments have been flown on the spacecraft of other agencies.

It would go beyond the scope of these articles to describe the Spacelab project which is being developed at the moment by the Agency but readers who are interested in this subject can obtain the relevant information from the Public Relations Office of ESA, 114, Avenue Charles-de-Gaulle, 92522 Neuilly-sur-Seine, France.

Part 2

ESA's Eight Scientific Satellites

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(Head of Space Science Department)

Before the launch of COS-B in August 1975, ESA (then ESRO) had flown seven very successful scientific satellites — and COS-B looks like being yet another success. Of the 51 experiments so far flown, none has experienced catastrophic technical failure and the vast majority have achieved the expected scientific return.

What we talk about below is a rather arbitrary selection of the results obtained under the headings " Sun-Earth Relationships " and " Astrophysics ". Also it should be noted that there has been excellent cooperation between experimenters in the various projects and fruitful exchanges with US and USSR scientists.

SUN-EARTH RELATIONSHIPS

While the study of distant astrophysical objects is very exciting, the investigation of sun-earth relationships is, in a way, more compelling because of the immediately observable response of the earth's environment to changes on the sun. This is particularly true in northern Europe when, for example, the auroral lights in the sky every night oblige the observer to wonder what gives rise to such a dynamic multicolour display. It is hardly surprising then that ESA's first seven satellites have carried a large number of experiments to study the earth's magnetic surroundings and their response to changes on the sun and in the interplanetary medium between sun and earth.

Less than 20 years ago, it was believed that the earth was surrounded by a dipole magnetic field which gradually weakned uniformly in all directions away from the earth into the vacuum of space. Spacecraft measurements have shown, however, that the sun continuously blows out a stream of plasma (the solar wind) at speeds around 400 km/s, and this plasma squeezes the earth's field into a shape someting like that shown in Fig. 1. There is a continuous struggle for supremacy between the wind, which may briefly reach speeds as high as 1500 km/s, and the magnetic field. The region close to the earth where the magnetic field remains in control is the magnetosphere, and its boundary with the solar wind is the magnetopause. When the sun produces a strong gust in the wind, the resulting change in the shape of the magnetosphere manifests itself on the earth as auroral lights, as disturbances in radio communication, and as magnetic field changes, which can, on occasion, be large enough to trigger safety devices in national electricity grids. There is too a growing suspicion that the sun exerts a very direct control on the earth's weather patterns.

Although many satellites have been flown through the magnetosphere in recent years, allowing the broad picture to be constructed, new fea-

	Launch date	End of useful life	Mission
ESRO-II	May 1968	May 1971	Cosmic rays, solar X-rays.
ESRO-IA	October 1968	June 1970	Auroral and polar cap phenomena, ionosphere.
ESRO-IB	October 1969	November 1969	As ESRO-IA.
HEOS-1	December 1968	October 1975	Solar wind, interplanetary magnetic field, bow shock.
HEOS-2	January 1972	August 1974	Polar magnetosphere, neutral point, interplanetary medium.
TD-1	March 1972	May 1974	Astronomy (UV, X- and γ-ray).
ESRO-IV	November 1972	April 1974	Neutral atmosphere, ionosphere, auroral particles.

tures are still appearing and the physical mechanisms producing the picture are very poorly understood. For example, it is still not clear even where the very high energy particle belts — discovered by Van Allen in the very first satellites — get their enormous energy in the first place. Much remains to be learned in the vast plasma laboratory accessible to us in the earth's surroundings. This information can then be used in, for example, understanding the processes underway in inaccessible stars and in increasing our knowledge of the containment of plasmas by magnetic fields.

A few of the main sun-earth results obtained by experiments flown on the ESRO-II, ESRO-I, HEOS-1 and 2 and ESRO-IV spacecraft are described below.

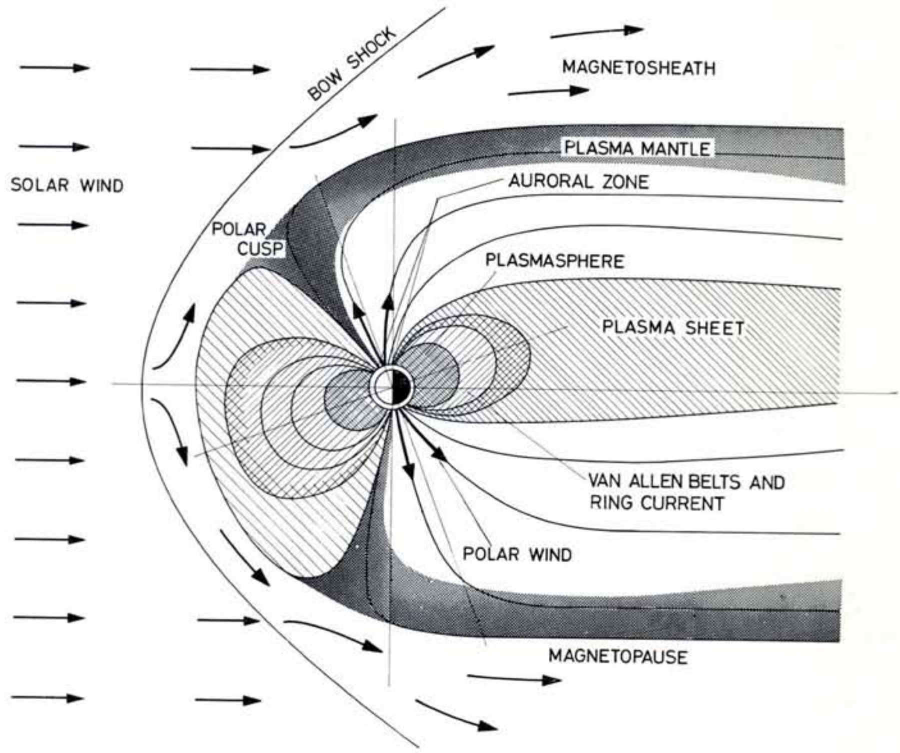

Fig. 1 *Noon/midnight cross-section through the magnetospheric plasma distribution. Note the plasma mantle discovered by HEOS-2.*

Auroral Zone and Polar Cap

The auroral zone occupies a band of latitudes between about 65° and 70° and extends all the way around the earth in longitude. Poleward of the auroral zone is the region generally called the polar cap, and equatorward are the stably trapped Van Allen belts of high-energy particles. Reference to Fig. 1 shows that the Van Allen belts are located in the dipole field of the earth, while the polar cap is magnetically connected to the magnetotail, which has been dragged out by the solar wind. Thus, the auroral zone in fact marks the boundary of the region where the solar wind influence almost ends and the dipole field takes control. It is scarcely surprising then that when the sun gives an extra push, its effects show up most vividly in the auroral zone.

The variability of the position of the auroral zone (Fig. 2) and the nature of the particles giving rise to the aurorae have been very successfully investigated by ESRO-1.

In the years just preceding spacecraft flights, it was suspected that solar particles of some sort arrived over the polar cap. Their arrival in discrete regions was mapped by the effects they produced on the local ionosphere. Some of the strange arrival patterns were understood better when the magnetic divide between the dipole field and the magnetotail was discovered. However, major advances were made by the combined efforts of experimenters on HEOS-1, ESRO-II and ESRO-I. HEOS-1 was able to measure the solar particles in interplanetary space directly and to see in what strength and from which directions they arrived. ESRO-II and ESRO-I passing over the polar cap close to the Earth were able to measure directly when and how these same particles arrived over the polar caps. Detailed computer calculations were made to plot the particle travel routes from their arrival just outside the magnetosphere until their appearance at the polar cap close to the earth. Experiment and theory have fitted beautifully and, at least for the higher energies, the means by which solar particles reach the earth now appear to be well understood.

Magnetospheric Structure

Theory predicts that, in the region where the dipole field ends and the polar magnetotail field begins, there exists a "neutral point". At this location the magnetic field becomes zero and charged particles therefore pass without hindrance. The HEOS-2 satellite, which operated flawlessly between January 1972 and August 1974, was the first deliberately flown to pass through the neutral-point region and the magnetospheric regions directly above the Earth's north pole. It has obtained several new and exciting results.

One of these is that the region of near-zero magnetic field indeed exists and is funnel-shaped. As such, it is probably more adequately described as a neutral "point" than as a neutral cusp region extending round the earth from noon through a broad range of local times.

An entirely new region not predicted by theoreticians has been discovered by the sophisticated plasma experiment on HEOS-2. This region (Fig. 1) has been called the plasma mantle because of the way it drapes around the outer regions of the polar magnetosphere. It was previously believed that plasma did not penetrate the magnetopause — at least in any ordered sort of way — but within the plasma mantle there is always seen a distinct plasma flow at velocities around 100 km/s and in a direction down the magnetotail away from the earth. The mantle can extend into the magnetotail for several earth radii from the magnetopause, and this thickness varies with conditions in interplanetary space.

At the magnetopause, which is the outer boundary of the plasma mantle, another HEOS-2 experiment has found that a layer of high-energy electrons is always present and becomes very intense when geomagnetic activity is high. Again this did not appear in the theories previously developed. So far, we are unable to say whether the electrons are on their way out of the Van Allen belts, or whether they are being accelerated just where we find them.

The discovery of these two previously unsuspected regions and associated phenomena indicates that quite

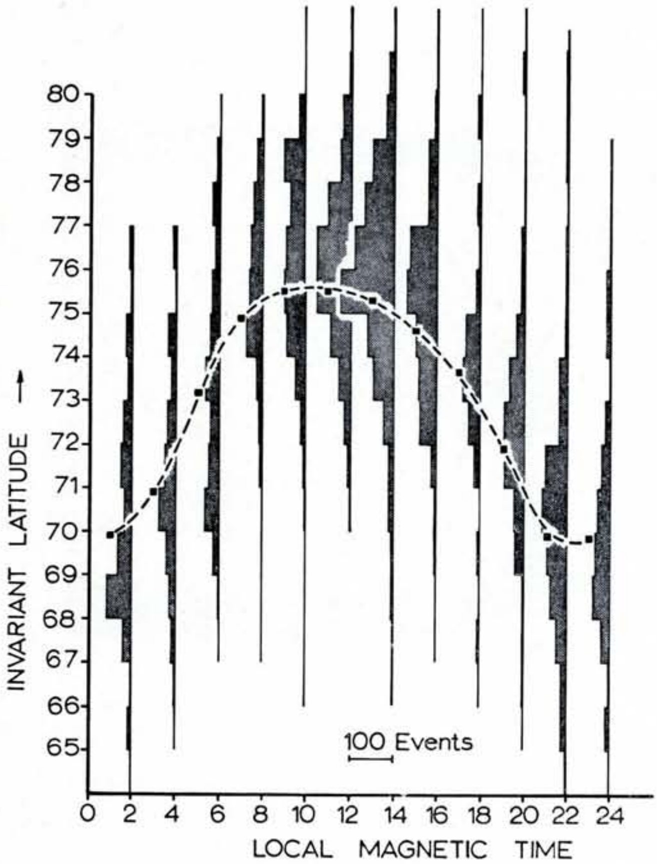

Fig. 2 *Diurnal variation of the poleward boundary of the radiation belt for 40 keV electrons.*

a few surprises may remain before the dynamics of the magnetosphere are properly observed, let alone explained.

Interplanetary Medium

The experiments of HEOS-1 and HEOS-2 have made major contributions to the study of the interplanetary medium — that region filled by the solar wind and the sun's magnetic field carried along with it. Typically, near the earth, the interplanetary magnetic field is seen to point toward the earth for about seven days. This " sector structure " of the field, with about four sectors appearing in each solar rotation of 28 days, is somewhat of a mystery, which may be difficult to unravel before we can make measurements beyond the ecliptic plane, from which the earth never departs by more than 7°. The magnetometer on HEOS-1 has operated perfectly for almost seven years and this stretch of continuous data, combined with similar excellent data from HEOS-2, has provided a wonderful opportunity to study how the interplanetary field evolves over the solar cycle. The data have been placed in the world data centres and are being used worldwide to support a great many studies in several scientific disciplines.

One of the most interesting results here, relates to the modulation of the cosmic radiation over the solar cycle. At sunspot maximum, the radiation able to penetrate to near the earth is very significantly less than that which arrives at sunspot minimum. It was first thought that this could be explained by changes in the solar wind and interplanetary field, which at solar maximum provided a stronger obstruction to the arriving radiation. However, the HEOS data have shown that the changes in magnetic field and solar wind observed in the ecliptic plane near the earth are far from sufficient to explain the observed variation in cosmic radiation. We are obliged to conclude that most of the important changes take place far out of the ecliptic.

The sun sometimes emits very high energy particles which can, on occasion, reach the earth within a few minutes. However, the travel time to the earth varies tremendously from event to event, and we find it difficult to sort out whether the differences are due to differing starting conditions at the sun, or whether the particle travel routes through interplanetary space vary sufficiently to explain the observations. Study of the combined data from the high-energy solar particle experiment, the magnetometer and the solar plasma experiment on HEOS-2 has provided significant further understanding of the particle transport in the interplanetary medium. It has been found that when the solar wind blows three-dimensional snake-like " tubes " in interplanetary space, the solar particles follow these obediently and show great reluctance to pass from one tube to its neighbours. The tubes may get entwined in such a way that the earth sees these particles very late after the solar event, or not at all.

The Earth's Atmosphere

The EOS-IV experiments rescued from the ill-fated TD-2 satellite proposal have combined in an excellent way to produce some outstanding results at this stage. Data analysis which still has a long way to go, has been greatly facilitated by the faultless performance of the tape recorder during the 17-month satellite lifetime. This is the first occasion on which an instrument measuring the neutral atmosphere has enjoyed a completely successful flight and the intimate relationships between the neutral atmosphere and the ionosphere (charged atmosphere) have been remarkably demonstrated. A world map of neutral gas densities above 250 km — the first of its kind — is being prepared. Until now, we have had to rely on models of the atmosphere guessed at from, for example, the drag exerted on spacecraft.

Taking one result as an example, the ionosphere has been probed for many years by radio waves sent up from the earth. Above some critical frequency, the waves penetrate right through the ionospheric layers and this critical frequency has been taken as a measure of the amount of ionisation present. Surprisingly, the correlation between ionospheric storms and magnetic storms has not been very good. The ESRO-IV neutral mass spectrometer has found that the ratio of neutral oxygen to nitrogen (O/N_2) provides a very good measure of neutral atmospheric heating (atmospheric storm effects). A very close correlation has been found between the O/N_2 ratio and the critical radio frequency required to penetrate the F_2 layer in the ionosphere (Fig. 3). This is just one of the many results showing how the neutral and charged atmospheres are closely related.

ASTROPHYSICS

During the past ten years radio astronomy techniques have led to dramatic advances in astrophysics including the discovery of quasars and pulsars. The availability of satellites has made it possible to study these exotic objects in wavelengths previously cut off from detection by the earth's atmosphere. In 1971 the NASA satellite Uhuru found X-ray binary stars which eclipse each other as they rotate and behave in such a way that astrophysicists think that one of the pair of stars may in some cases be a "black hole". A black hole is the ultimate end of a star which has squeezed itself under its own gravity to a size where its internal gravity pull is so strong that even light is incapable of escaping.

ESA has plans to continue these exciting X-ray studies by pinpointing the locations of sources with its Exosat satellite. However, its main contribution to astrophysics so far has been the highly sucessful TD-1 satellite launched in 1972. (It did, nevertheless, with the very first satellite ESRO-II successfully fly an experiment to study the galactic magnetic field and the acceleration processes taking place there.) The main experiments of TD studied the sky in the UV region where it was thought some of the most interesting processes in stellar atmospheres would produce signatures.

One of the TD experiments provided by British and Belgian scientists set out to survey the whole sky as seen through "wide-open" UV eyes. The experiment has been an outstanding success, exceeding the expectations of its builders, in spite of some initial worries. One of these was the failure of TD's tape recorders. This was overcome by the real-time ground station network set up world-wide to such good effect that 95 % of the sky has been surveyed. The other big worry was that the experiment was to examine very faint stars against a fully sunlit background. The sun baffle worked so well that stars down to a magnitude of 10.5 were measured — compared with a design aim of the 9th magnitude. At this time, 15 000 stars have been examined and a large community of guest observers has been involved in the studies. A Bright Star (UV) Catalogue will be published by ESA in the near future, and a faint star catalogue is being planned. These will be of very significant value to the world astronomical community.

By plotting the flux radiated by a star at various wavelengths it is possible to allocate a spectral type and hence a temperature to that star. (These types were historically, for no very good reason, assigned the labels — from hot to cold — O,B,A,F,G,K,M. Only astronomers can remember this, and ordinary physicists have to remember "Oh Be a Fine Girl Kiss Me"). It was found by statistical analysis that the plotting of star brightness against O, B, A... etc. spectral type placed most stars on a particular curve. The curve is referred to as the Main Sequence, and the plot is called the Hertzsprung-Russel diagram. This relationship is used in a rather basic way in, for example, determining the distance to a star. It ought therefore to be valid at all wavelengths. The UV experimenters on TD-1 have made a special study of stars of spectral type A (as defined from visible observations) and have found that the UV fluxes differ enormously from star to star (Fig. 4). In other words, these stars do not lie tidily on any part of Main Sequence. This is an interesting result and tempts the nonprofessional astronomer to wonder whether our ideas might not be different had our eyes been tuned to accept a different wavelength range.

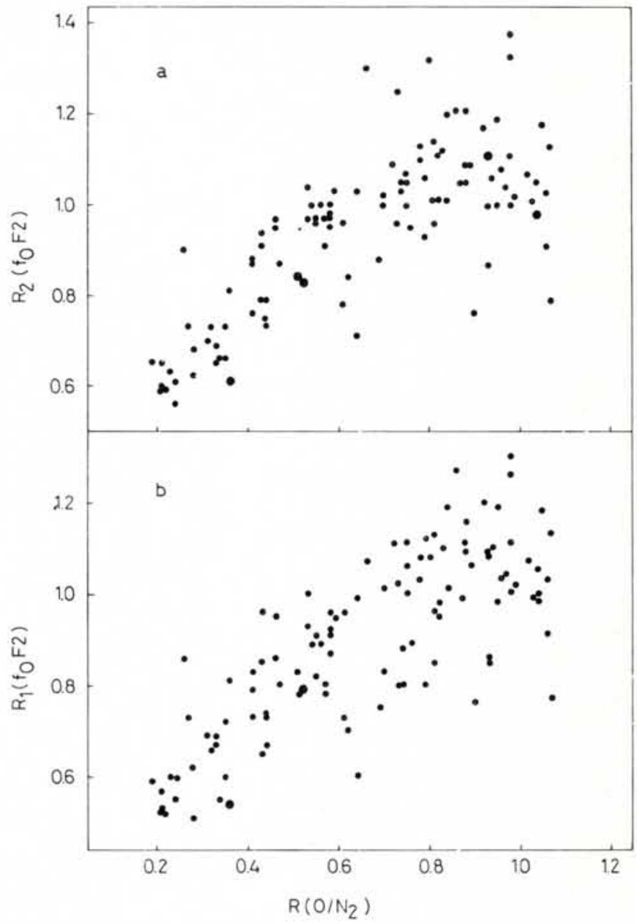

Fig. 3 *Correlation between changes in the critical frequency of the F_2 layer (f_0 F_2) and in the O/N_2 ratio: (a) R_2 (f_0 F_2)* versus R *(O/N_2) and (b) R_1 (f_0 F_2) versus R (O/N_2).*

A complication that arises in studying radiation arriving from distant stars is the understanding of what happens to that radiation en route, and the degree of degradation or interstellar extinction. One might reasonably have expected the amount of interstellar extinction suffered to depend on the position of the star on the celestial sphere. Another surprising TD result is that the amount of extinction seems to vary very little indeed with different viewing directions in the Galaxy.

A second highly sophisticated ultraviolet experiment on TD was provided by Dutch astronomers. This experiment locked on selected stars and steered itself so precisely that it was possible to measure lines in stellar spectra with a resolution close to 1 Å. While the British/Belgian experiment concentrated mainly on statistical studies of the whole sky, the Dutch experiment examined individual stars in great detail. One of the features outstanding in the observations is the strength of the spectral (absorption) lines of doubly ionised magnesium. Detailed study of the broadening and the shift of these lines has yielded a wealth of information on the stellar atmospheres. For example one star, α Cygni, has been found to be losing mass at a very significant rate, i.e. its atmosphere was seen moving away from it. In γ^2 Velorum, a spectroscopic binary consisting of stars clas-

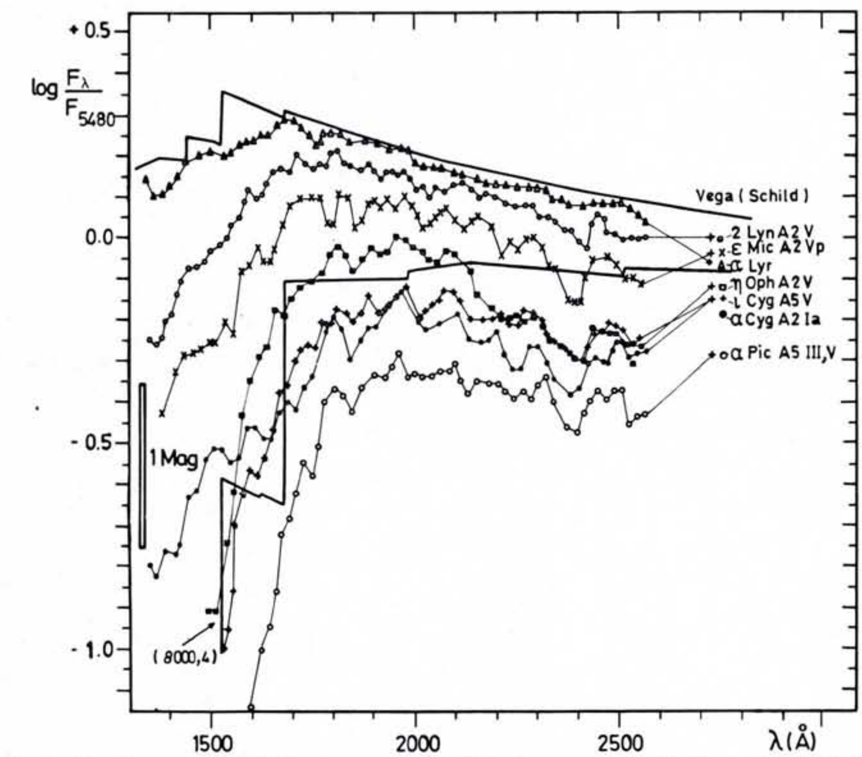

Fig. 4 *Absolute energy distribution for some A2 and A5 stars compared with Vega and predicted flux from two theoretical model atmospheres.*

sified as O9 and WC8, the O-type star was found to be well described by existing models of stellar atmospheres (built up largely on visible spectral data), but the UV flux from the WC member of the pair was much higher than expected. This could be due to a higher than expected amount of helium in its atmosphere.

Two further TD experiments produced results of significant astrophysical interest. One observed the abundance of cosmic-ray nucleii. The relative abundances of these particles tell the experimenters how long they have existed and the regions through which they have travelled on their way to the earth. The second observed solar X-ray bursts with a time resolution of just greater than 1 s. This enabled the experimenters to discover that an X-ray event on the sun was made up not of one large initial burst which then gradually decayed, but of a series of largely unrelated short-lived bursts. This result indicates that the particles producing X-rays in the solar atmosphere are not all injected then at the same time. The sun is our nearest star and detailed results like this, which we cannot hope to obtain from distant stars, will help piece together the picture of how stars in general behave.

COS-B

COS-B is the first European satellite to carry a single complex experiment developed by a collaboration of research institutes. Its primary mission is to study high-energy gamma radiation from the Galaxy, from known or postulated point sources and the diffuse background radiation. The position of gamma-ray sources is measured in order to investigate where the cosmic radiation originates and a study of the gamma energy spectrum helps decide which processes take place in the production region and en route to the earth.

The satellite was launched on 9 August 1975 and scientists have been studying a heavy flow of high-quality data since a few days after launch. Both spacecraft and experiment are operating perfectly and gamma and X-rays were measured arriving from known source positions in the sky during the early weeks of operation. Since then the satellite has carried out a comprehensive study of selected regions of the Galactic disc and has just embarked on an exploration of the relatively unknown regions outside the Galaxy.

The regions so far selected for study include several where pulsars have been seen at X-ray wavelengths. In two cases (the Crab and Vela supernova remnants) the experiment has detected enhanced emission from the direction of the pulsar and the experimenters will be searching the data for evidence of gamma-ray pulsations. Other regions studied contain binary star systems in which X-ray sources show occultations, and one contains an X-ray source which has been suggested as a possible black hole. The experimenters are monitoring the incoming data closely for any first signs of interesting effects in any of these peculiar objects. They are also watching closely for those unexplained dramatic and apparently random gamma-ray bursts detected by American satellites in the past few years.

A problem in trying to measure gamma rays from a satellite is the high background of charged particles but in COS-B the background count has been reduced to a level where we can confidently expect to make the measurements hoped for.

Part 3 Satellites under Development

GEOS

GEOS is a sophisticated and ambitious satellite which will carry seven experiments into a geostationary orbit during 1977. It will be the first purely scientific geostationary satellite and as such has been adopted as the 'reference' spacecraft for the International Magnetospheric Study (IMS). The IMS is a world-wide programme combining spacecraft, balloons, sounding rockets and ground-based observatories in an attack on the basic problems of magnetospheric physics.

ISEE

Single satellite measurements have been unable to sort out spatial from time variations and to determine, for example, wavelengths undistorted by spacecraft and wave relative velocities. ESA and NASA have put together the International Sun Earth Explorer (ISEE) mission to attack such problems. One spacecraft will monitor interplanetary phenomena while two others will, as a pair, simultaneously study the behaviour of the earth's magnetosphere in response to the interplanetary changes.

IUE

The International Ultraviolet Explorer (IUE) is a joint NASA, United Kingdom and ESA venture due for launch in late 1977. The scientific aims are to study high-resolution