Low Cost Mission to Study the Dynamics of the Earth's Radiation Belts

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The magnetosphere as a whole presents researchers with an enormous variety of natural phenomena that will surely challenge our individual and collective imaginations for decades to come.
M. Schulz, in Geomagnetism,
J.A. Jacobs (ed.), Academic Press, 1991

Introduction

Perhaps the least well explored region of the Earth's magnetosphere is its radiation belts despite their being the first major discovery of the space era. There has only been a single space mission, CRRES, in the last twenty years which has been dedicated to investigating the source and loss mechanisms and the dynamics of the energetic particles trapped in the Earth's magnetic field. The reason was probably that the radiation belts were perceived to be relatively stable and therefore less dynamic and less interesting than the physics of the outer magnetosphere. The short lived CRRES mission has changed that perception. In particular the events of following the large geomagnetic storms in March 1991 showed that the distribution of trapped particles can change dramatically within a few hours in the inner radiation belt and that the energies involved can be many tens of MeV. It is clear that solving the problems of the transport and acceleration of very high energy particles in the radiation belts presents a significant scientific challenge.

The radiation belts are not only scientifically important; they create a number of difficult practical problems for the operation of applications satellites. Over the last ten years the use of electronic components with large scale integration on the chip, and correspondingly smaller volumes for the junctions and tracks has made them more vulnerable to the effects of bombardment by penetrating particles from the radiation belts. Yet just at the time when engineers are asking scientists for information about the level of radiation their spacecraft are likely to encounter, the scientists are finding that their estimates, based on observations made before 1970, are inadequate or even misleading. Further investigation of the radiation belt is therefore timely both for scientific and for practical reasons.

The CRRES spacecraft carried a comprehensive set of instruments to investigate the characteristics of the radiation, its effect on microelectronic circuits and the plasma environment in which the energetic particles are found. Its total payload weight alone was substantially more than 100kgs. Unfortunately the spacecraft ceased operations after just 15 months, before it had completed a circuit in local time. The feeling of the participants following the termination of the observations is that the curtain which was raised briefly on an unexpectedly dynamic scene, has been dropped again before the picture could be properly brought into focus.

The need now is for further observations but we propose a different scientific approach and an innovative programmatic approach.

The scientific need is less for an all embracing set of instruments than for sharply focussed measurements at a wide range of locations in the magnetosphere; at a number of locations simultaneously; and over a long period of time. Rather than one comprehensively instrumented mission, in one fixed orbit, we propose an ongoing sequence of small satellites, lightsats, carrying one or two instruments each. They would take advantage of any low cost launch opportunities, such as the Ariane ASAP and be launched into as wide a range of orbits as possible. In some circumstances advantage could be taken of the availability of space on other missions to place an instrumented package on an operational spacecraft with minimal impact on the main objectives. Such packages have been deployed on Meteosat F2 and P3 and are planned for a comprehensive series of Russian operational spacecraft in the Patrol project.

We propose that ESA;

1) coordinates the programme by selecting laboratories to provide the instrumentation for and operate a particular satellite; 2) seeks out the launch opportunities; 3) maintains the data base and facilitates access to the data by all interested scientists, not just those providing hardware. 4) coordinates the procurement of the lightsats in European industry. We propose that the programme be supported at a fixed level of annual expenditure rather than at a fixed number of spacecraft. The programme would be managed through ESA both scientifically and financially in such a way as to maximise the scientific return, and to adapt to the changing circumstances, over the period of the programme. The period should be at least five years in the initial phase with the possibility of extension to 11 years to cover a complete solar cycle. The spacecraft bus should be procured by ESA from smaller European aerospace companies and institutions, several of which are already developing spacecraft in this class. We note in particular the STRV spacecraft produced by DRA at Farnborough and the UoSat series of spacecraft produced at the University of Surrey. The scientific instruments would be provided by nationally-funded research laboratories. The operations would be carried out by the research groups themselves, communicating directly with the spacecraft using a small satellite communications set of dish antenna, receiver/transmitter and PC computer to collect the data and control the instrument. In this way, all phases of the deployment of such a spacecraft could be closely linked with the educational programme at a University. The facilities already exist at University College London and the University of Surrey in the United Kingdom to take advantage of such an opportunity through their BSc and MSc degree courses. The advantages of such a programme are;

1) it pursues first class scientific objectives on a modest scale of costs, providing excellent value for money. 2) it provides "hands-on" experience for the next generation of aerospace engineers, with projects completed in a short period of time 3) it stimulates the development of innovative techniques in science instrumentation and space technology by allowing flight tests in a reasonable timescale.

1 Scientific objectives

~~1.1 Introduction~~

The study of the Earth's radiation belts received fresh impetus with the advent of the CRRES spacecraft. The new observations are of great scientific interest within the field of space plasma physics; in addition they are important for the selection of electronic components for any spacecraft planned to fly near (eg geostationary orbit) or through the radiation belts. CRRES produced much interesting new science during its abbreviated lifetime, including the following:

- Completely unexpected phenomena were seen in the radiation belt regions. For example, a huge solar disturbance in March 1991 caused a third, new radiation belt to form in between the intense inner and outer zones [Blake et al, 1992]. The belt formed within one minute of the arrival of an interplanetary shock at the magnetopause (Figure 1). The new belt persisted for at least 6 months afterwards (see Figure 2) and some of the associated particles will remain trapped in the Earth's environment for years.
- A highly variable flux of particles in the 1-10MeV range was seen in the outer regions of the radiation belts [Brautigam et al, 1992]. This is contrary to previous understanding which predicted a fairly stable flux at these energies. The data show that the flux levels can change by more than an order of magnitude, both up and down from one day to the next. The changes occur over a wide range of L values from L=2.5Re to L=6.5Re. This indicates substantial acceleration, and a very dynamic situation in contrast to previous expectations.
- Observations show that the present radiation belt models are incorrect, sometimes underestimating and sometimes overestimating the particle fluxes which are seen (Gussenhoven et al, 1991).

All of these discoveries have major implications for space plasma physics. The first two emphasize that the radiation belt region is in fact very dynamic with changes occurring on rapid timescales. This will have implications in studies of other planetary magnetospheres such as Jupiter.

A system of Earth orbiting spacecraft monitoring plasmas and energetic particles over a long timescale and at different local times can be expected to reveal significant new discoveries and will improve our existing understanding of this important region.

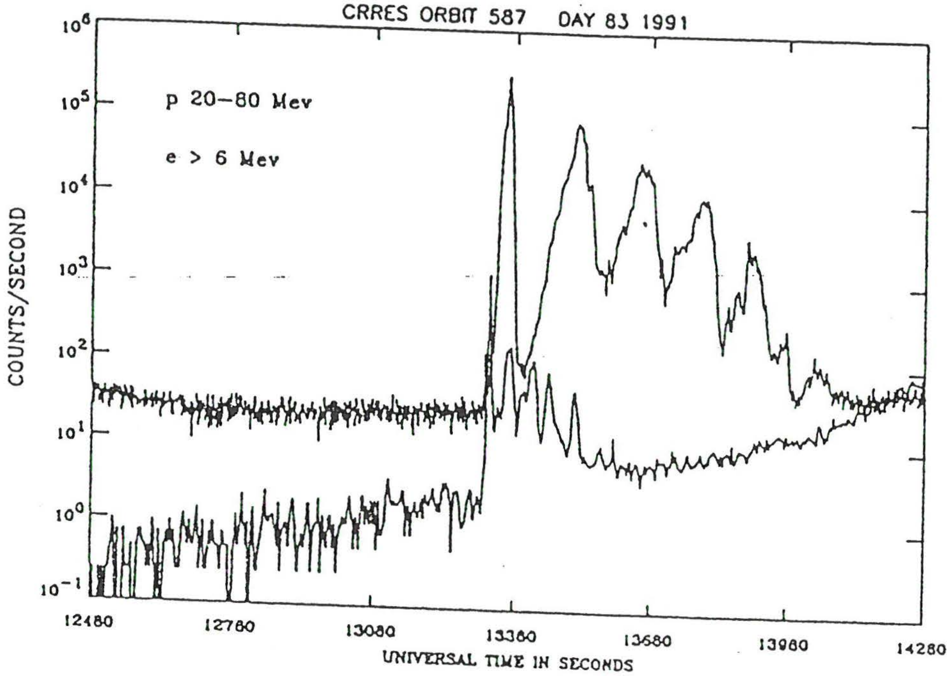

Figure 1

A plot of the Count rate in the 20-80 MeV proton detector and the electron detector for energies greater the 6 MeV as CRRES moved inbound at the time of arrival of a strong shock in the solar wind. The enormous increases in count rate occurred within approximately one minute of the arrival of the shock at the magnetopause. At the time the spacecraft was at an L value of 1.65RE. This shows that very energetic effects can occur extremely rapidly, deep inside the magnetosphere.
(Blake et al 1992)

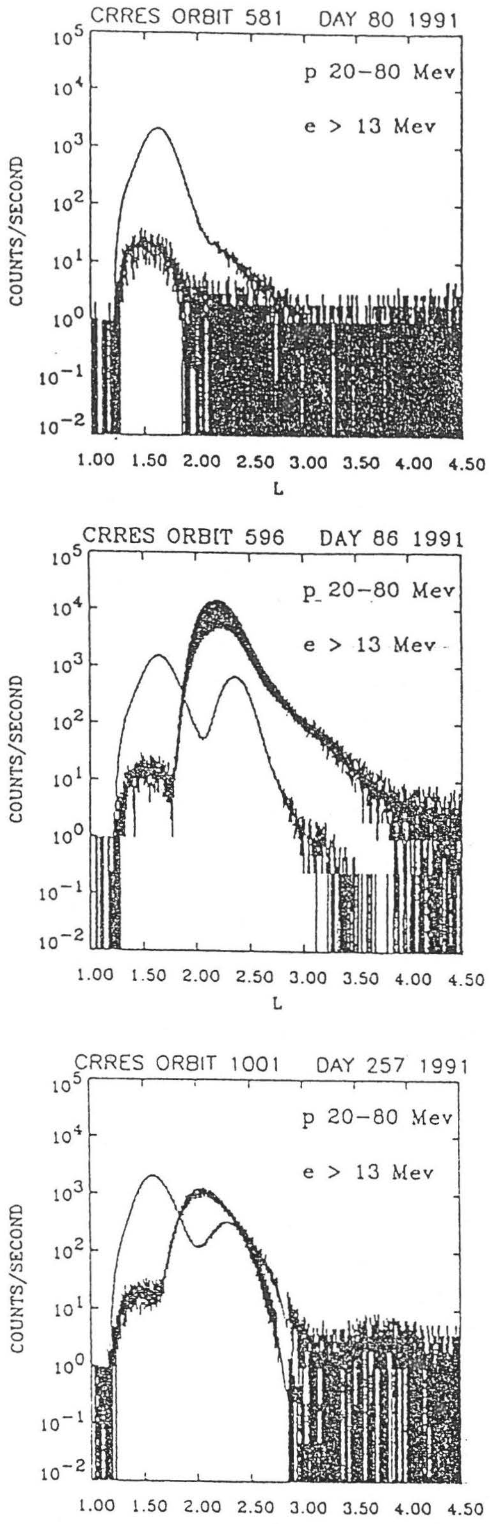

Figure 2

The three panels show the radial profiles for the 20-80 MeV proton channel and the electron E > 13 MeV channel for the orbit immediately before the event shown in figure 1, the one just after, and one six months afterwards. There was a major change in the distribution caused by this event whose effects are likely to persist for a considerable time.

1.2 Review of the radiation belts

1.2.1 The inner zone

Energetic protons with energies up to several hundred MeV are the most important component of the "inner zone" or inner belt. In the equatorial plane this belt extends out to a geocentric radius of about $4\,R_{\mathrm{E}}$, with the maximum flux of protons with $E_{\mathrm{p}} > 10\,\mathrm{MeV}$ occurring at about $2\,R_{\mathrm{E}}$. This is a fairly stable population but is subject to occasional perturbations at the belt's outer edge due to geomagnetic storms.

The source of the high energy protons is probably *Cosmic Ray Albedo Neutron Decay (CRAND)*, but new physical models are necessary to check the validity of this theory which was proposed in the sixties. According to the CRAND theory, very energetic cosmic ray particles, mainly protons and other ions with energies of hundreds or thousands of MeV, collide with the nuclei of atmospheric gases, generating neutrons. The upward "albedo" neutron flux is of the order of $1\,\mathrm{neutron\,cm^{-2}\,s^{-1}}$ and depends on geomagnetic latitude since charged cosmic rays find it easier to penetrate the geomagnetic field at higher latitudes. Neutrons have a lifetime of less than 1000 s before decaying into an electron and a proton. It is found (Walt & Farley 1978, Schulz & Lanzerotti 1974) that this process may deposit electrons and protons on geomagnetic field lines at a sufficient rate to account for the observed steady-state flux intensities if inward radial diffusion and energization are also accounted for. Note, however, that the CRAND theory does not account for the presence of trapped ions other than protons. A physical theory describing the origin of these more massive trapped ions is still lacking.

The inner edge of the belt is an important region for space missions. It is dominated by the *South Atlantic Anomaly (SAA)*. This is an area of enhanced radiation caused by the offset and tilt of the geomagnetic axis with respect to the Earth's rotation axis. The first-order dipole approximating the geomagnetic field is displaced from the centre of the Earth by 515 km in the direction of the north Pacific and the geodipole axis is tilted 11° with respect to the geographic N-S axis. This brings part of the inner radiation belt and, most importantly, its energetic proton component to lower altitudes.

Energetic protons have large gyroradii. In the SAA, field lines dip at an angle into the atmosphere. To reach a particular point, energetic protons must gyrate over large distances. The sense in which a proton gyrates (left-handed w.r.t. $\boldsymbol{B}$) means that those coming from the west must have gyrated from above the point while those arriving at the point from the east must have gyrated from below. Particles from below will have encountered a much greater atmospheric density than those from above and so will be more likely to be lost in collisions. The result is that the flux from the east is larger than from the west and particle fluxes are strongly anisotropic at low altitudes (Heckman & Nakano 1965). The process obviously depends on gyroradius, so higher energy particles display a larger anisotropy. It also depends on atmospheric density, so the anisotropy decreases with increasing altitude.

Another component of the low-altitude anisotropy is a result of the fact that particles in the SAA are all near their mirror points. If they were not, they would quickly be absorbed by the atmosphere as they spiraled to lower altitudes. Therefore the distribution of particle pitch angles in the SAA is strongly biased towards 90°, with an approximately Gaussian angular distribution of particle fluxes of half-width $\sim 12^\circ$ (Hess 1968). So not only is there a strong east-west asymmetry, but particles arrive mostly perpendicular to $\boldsymbol{B}$.

For many space missions these effects are not important since random orientations of spacecraft average the effect out. However, the International Space Station and other important missions maintain an orientation so that one spacecraft axis is approximately along the velocity vector (in a roughly eastward direction) and another facing Earthwards. This means that the anisotropy effects do not average out and the trailing side of the space station will experience a higher flux than the leading side. This may have implications for astronaut exposure in the station. The *Long Duration Exposure Facility (LDEF)*, a large unmanned structure, had a similar orientation and radiation exposure data from its experiments are proving very valuable. Armstrong et al. (1992) recently presented disagreements between LDEF measurements and models, for both flux magnitude, and east-west asymmetry.

Fluxes of trapped protons at low altitude are lower at the maximum of the solar activity cycle than at the minimum because higher neutral atmospheric density at solar maximum leads to enhanced losses and so to reduced proton fluxes. At low altitudes, on the inner edge of the radiation belts, particle fluxes rise very steeply with altitude and small errors in computing locations can give rise to large errors in particle fluxes. This is a problem because of slow changes in the geomagnetic field offset and tilt and in the strength of the geodipole moment.

Therefore, the situation today is no longer as it was when the model data were acquired. Although the drift of the dipole centre towards the north Pacific leads to an apparent lowering of the "inner edge" in the SAA, in reality the atmosphere absorbs any lowered particles while CRAND and diffusion replenish the population. It is not possible to use updated geomagnetic field models with old particle data so current particle models do not really model the situation as it is today.

One important effect of secular variation is the change in the geographic location of the SAA (Konradi et al. 1992, Dyer et al. 1992). Konradi et al. (1992) reported on shuttle observations of a 6.5° westward shift of the centre of the SAA compared to model predictions, based on data from 30 years earlier. Switch-off of scientific instruments and astronaut "spacewalks" are timed to avoid the SAA. Problems may arise since it is possible for the SAA to be encountered a complete orbit earlier than expected. The observed westward shift is close to that expected from the geomagnetic field evolution. At the same time, Konradi et al. (1992) reported that the ratio of measured to predicted flux in the SAA was found to be 1.55. Here, the ratio of measured to predicted flux in the SAA was said to be between 1.7 and 2.3, based on analysis of activation of LDEF materials.

The low altitude part of the current solar maximum model AP-8 MAX is based solely on the data provided by MPE from the AZUR satellite. These data cover the period from November 1969 to June 1970 in a 103° orbit of 3145 km × 383 km, from detectors measuring flux perpendicular to $\boldsymbol{B}$ (Hovestadt et al. 1972). Disturbed days were also removed from the data.

Daly & Evans (1993) recently reported that there are large errors in the interpolation routines supplied with the current models when used at low altitudes.

All these problems taken together mean that radiation belt empirical modelling of the inner zone is in a confused state. Physical modelling awaits quality data to be tested.

1.2.2 The outer zone

The most important component of the "outer zone", or outer belt, is energetic electrons with energies up to a few (~ 10) MeV. The belt extends to a geocentric radius of about $10\,R_{\mathrm{E}}$ in the equatorial plane, with the flux maximum for electrons with energy above 1 MeV occurring at about $4\,R_{\mathrm{E}}$. This is a much more dynamic population than the inner-zone protons and is the product of injection events following geomagnetic storms or substorms.

Baker et al. (1986) reported some evidence linking enhancements in fluxes of energetic outer zone electrons with high-speed streams in the solar wind and through them with a source on the Sun, or at Jupiter which has particularly intense radiation belts and is known to supply energetic electrons to interplanetary space. However, the correlation between interplanetary fluxes and magnetospheric enhancements was subsequently shown to be poor (Christon et al. 1989) and an internal process for transport and energization seems most likely (Baker et al. 1989). This process has yet to be properly understood.

During an injection event, low energy electrons in the tail of the magnetosphere are accelerated Earthwards into the outer parts of the outer zone. There they are thought to undergo episodes of energization and inward diffusion due to the magnetic field perturbations which accompany substorms (Roederer 1970, Vampola 1989). Electrons can diffuse inwards while conserving the adiabatic invariants μ and I. Since B increases, the electrons gain energy, filling mid-altitude ($L \simeq 4\,R_{\mathrm{E}}$) drift shells [the L-parameter was introduced by McIlwain (1961)] with high-energy electrons. Another result is that electrons mirror closer to the geomagnetic equator, although subsequent pitch angle scattering due to wave-particle interactions can give them mirror points at lower altitudes (higher B) on field lines.

Shell-splitting, which shifts particles with different pitch angles from a common L-shell, can then have the effect of transporting pitch angle scattered particles outwards once more (Roederer 1970, p. 136). This outward diffusion results in no energy loss so that, according to this model, electrons will have made a net gain of energy in this circulation, thereby producing the fluxes of high energy electrons seen at high altitudes ($L \simeq 7\,R_{\mathrm{E}}$) (Baker et al. 1989). Of course, pitch angle scattering also results in the loss of particles if their new pitch angles are in the loss-cone, or results in trapping of previously untrapped, externally-injected particles.

Some electrons and ions also originate in the high-latitude ionosphere and move upwards along field lines to high altitudes where they participate in the diffusion, energization and scattering processes. There is also a smaller inner-zone of electrons which is separated from the outer zone by a "slot region" where enhanced wave-particle interactions cause pitch angle scattering of electrons into the loss cone, depleting this region. Outer zone electron fluxes are brought to low altitudes at high latitude by the geomagnetic field lines, meaning that outer zone electrons can be encountered by low altitude spacecraft as well as high altitude spacecraft.

The distortion to the Earth's magnetic field by the solar wind and various currents flowing in the magnetosphere gives rise to a significant diurnal (day-night) variation in particle fluxes since particle drift shells are no longer azimuthally symmetric, as was mentioned previously. As a result, a spacecraft in geostationary orbit often observes a quasi-sinusoidal daily variation in electron fluxes but this signature can disappear entirely at certain times. Often during disturbed periods the sunward side of the magnetosphere is compressed so that a geostationary spacecraft in this part of the orbit sees very low fluxes. On the other hand, intense increases can result from injection and energization processes. Therefore long-term averages are not a good way to describe the outer radiation belt environment. During storms spacecraft experience on-board anomalies as a result of electrostatic discharge following charge buildup.

The dynamic nature of the outer electron radiation belt, together with its diurnal variations mean that unless one is interested in long-term averages (such as provided by AE-8) some statistical description is desirable. This is especially true today when problems of deep dielectric charging (Fredrickson et al. 1991) and radiation background are of concern. CRRES flew for 14 months in a near-equatorial highly-elliptical orbit with an orbital period of 10 hours which took it from about 300 km altitude out to about 35000 km, so that it traversed the main parts of the inner and outer zones. Preliminary analysis of CRRES data has confirmed that the models badly need revision (e.g. Brautigam et al. 1992). In March 1991, a large geomagnetic storm occurred which resulted in the creation of a secondary proton belt between 2 and 3 R_{E}. This behaviour is not included in any modelling and is clearly of scientific importance as well as of practical importance to spacecraft passing through this region (Mullen et al. 1991). CRRES results vividly illustrate the dynamicism of the electron environment and the change in the morphology resulting from the March 1991 storm. There is also an apparent periodic surging of electron fluxes, possibly related to the 27-day rotation period of the Sun which drives changes in the solar wind. Blake et al. (1992b) reported a quite unprecedented observation made by instruments on CRRES. An almost instantaneous injection of electrons and protons with energies above 15 MeV into the region $L = 2\text{–}3\,R_{\mathrm{E}}$ was seen, and the data also implied that the electron energy spectrum continued up to at least 50 MeV.

Chiu et al. (1989) describe an effort to develop dynamic physical models of the outer-zone electron population, based on diffusion theory. This should provide a valuable aide to both understanding the physics of outer-zone electrons and to the development of models which are physically meaningful while being of use to the "application" community. Another approach is taken by Brautigam et al. (1992) who have constructed a number of quasi-static empirical models of the outer zone electrons to represent different magnetospheric activity levels. Although CRRES passes through low-altitudes, it does so so quickly that in its short mission the number of relevant data points is small. Therefore it is not able to contribute much to the analysis of the problems of the SAA modelling described above.

1.3 Comprehensive statistical mapping of the inner and outer radiation belts

The existing models of the radiation belts in the AP and AE series are based on data sets that generally are over twenty years old. Coverage across a wide range in L values was obtained by combining data from many different satellites, carrying an assortment of payloads (Vette 1991ab). The CRRES mission attempted to make measurements throughout the radiation belts using modern instrumentation. It observed dramatic time-dependent phenomena, particularly, the creation of a third radiation belt after a period of intense magnetospheric activity in March 1991 (Blake et al. 1992a, Gussenhoven et al. 1992). The rate of occurrence and decay of such events is not known.

The proposed mission aims to create improved models of the radiation belts, including quantitative assessments of the variability of the observed fluxes with time and their anisotropies at low altitudes. The 27 day variability (solar rotation) of radiation belt fluxes would be investigated. There is a clear solar cycle effect on geomagnetic activity as discussed by Vampola (1989). This should translate into solar cycle variations of the radiation belts.

There is a need for a satellite study with the following characteristics:

- modern instrumentation including
  - electrons up to 10 MeV, including pitch angle distributions,
  - ions up to 50 MeV/Q;

- a time-scale of a solar cycle (11 years), either by long-lived satellites, or by successive satellites with identical instrumentation;
- orbital coverage between 800 km and geostationary orbit.

1.4 Substorm injection event propagation

Substorms are the most likely sources of the energetic particles that make up the radiation belts. Substorm injection events (Fairfield 1992) are currently believed to originate in the tail, about 7 to 10 R_E from the Earth, and propagate earthwards. The electrons also experience an energy-dependent combined gradient and curvature drift in an eastward direction. Very large injections may be seen more than once (Blake et al. 1992b) as the drift motion takes the electrons round and round the Earth in what are termed *Drift Echoes.* The triggering mechanism of these injection events is not understood and needs a physical explanation to which a dedicated small mission would contribute. A satisfactory physical explanation for these dramatic magnetospheric injection events is a challenge. This study aims to investigate the statistics of substorm occurrence, the drift speed, drift propagation, drift echoes, energy dispersion, pitch angle effects, and losses associated with the propagation of the event.

This aspect of the study requires:

- a minimum of three but preferably more satellites covering the orbital range from 800 km to geostationary orbit with various separations, so that different positions along the injection event track can be sampled;
- electron analysers measuring from 30 keV upwards.

1.5 Energization of the radiation belts

It is likely, at least in the outer radiation belt, that plasma is first energized at lower altitudes and that it diffuses to higher altitudes by processes that are not yet well understood. This study aims to investigate this energization, to see if it is related to adiabatic compression of the magnetic field or large time dependent electric field intensifications. We also wish to study the diffusion of the plasma away from the region where it is energized, including associated pitch angle scattering.

This aspect of the study requires three or more satellites simultaneously looking at the outer radiation belt and positions deeper in the magnetosphere.

1.6 Origin of radiation belt ions

CRAND is generally cited as a source for 10–100 MeV protons. Early model calculations performed in the 1960's need to be confirmed using newer cosmic ray flux measurements and better atmospheric models than were available twenty years ago. It appears, however, that the stable CRAND source is not able to explain the dramatic enhancements of ion flux observed by CRRES. Information on mass and charge composition of trapped ions in the radiation belts would help to identify the additional sources of these particles. The relative importance of the solar wind and the ionosphere as reservoirs of energetic (accelerated) particles is not yet known. The anomalous cosmic ray component may be an important source. A dedicated mission like the one proposed here would be able to bring an answer to this key issue.

This aspect of the study requires an ion mass and energy analyser. Analysers that measure E/Q are not likely to be adequate.

1.7 Radiation belt precipitation rates

Flux is continually being lost from the radiation belts, mainly by diffusion into the loss cone and subsequent precipitation into the atmosphere. Two types of loss cones exist: injection into the direct loss cone causes the particle to be lost on its next bounce; injection into the drift loss cone causes it to be lost when its drift motion causes it to intersect the SAA. This study aims to measure rates of precipitation and diffusion into the loss cones.

This aspect of the study requires simultaneous measurements by a satellite in a polar low-Earth orbit (around 800 km) and satellite(s) which pass through the inner and outer radiation belts. The low-Earth orbiting satellite will frequently sample the 'horns' of the radiation belts. The LEO satellite would benefit by having high time resolution because it essentially sees a snapshot of the whole radiation belt structure as it swiftly crosses these horns. Such information would be used to infer the global status of the belts in a short time period. Ground-based observations of ULF/VLF waves can be correlated with the satellite measurements to study wave-particle interaction processes.

1.8 Study of the South Atlantic Anomaly (SAA)

The SAA is the aspect of the radiation belts that most strongly controls the radiation exposure of satellites in low-Earth orbit, and is also very interesting as a boundary between energetic particles and the neutral atmosphere. As such, it is an interesting example of magnetosphere-atmosphere coupling. The location of this region is known to change as the Earth's internal magnetic field changes secularly. This study aims to produce models of the SAA, investigate the sharp flux cut-off at the top of the atmosphere, and examine temporal changes. Measurements of pitch angle distribution will allow the East-West asymmetry to characterized.

This aspect of the study requires a polar low-Earth orbit satellite.

1.9 Other studies

- magnetopause crossing during compression events
- wave-particle interactions
- in situ measurements of ring current strength, providing information on magnetosphere-ionosphere coupling
- long term study of the ring current and correlation with solar and geomagnetic indices (pressure, density, velocity of the solar wind)
- micro-bursts of relativistic electrons
- engineering investigations: spacecraft charging, radiation effects
- comparisons with ground-based geomagnetic and auroral observations
- correlation between earthquake epicentres and regions of high energy particle precipitations from the radiation belts

1.10 Possible use of MIR

A detector could be included on the MIR station. The benefits of simultaneously flying on MIR include:

- There will be many "conjugate points" when MIR and GTO spacecraft, in very different orbits, simultaneously encounter the same geomagnetic field lines. Field lines control the radiation belts and these unique observations will allow us to construct reliable models to extrapolate to all latitudes.
- The MIR orbit allows mapping of the SAA, the main radiation source for low altitude missions, which has recently been shown to be badly catered for in current models.
- The MIR orbit allows mapping of the directionality in the low-altitude energetic proton environment.
- MIR provides for long-term measurements rather than brief measurements made on "directionally impure" shuttle flights.
- The MIR orbit is likely to be an important feature of future ESA programmes.

2 International partners

It is anticipated that this mission will be an independent European activity. However, normal scientific cooperative links will be encouraged with U.S., Russian, and Japanese investigators engaged in complementary studies, e.g. other magnetospheric satellites.

The team of Co.-I.'s could be enlarged in order to have a wide geographical distribution and additional expertise of experimenters and interdisciplinary scientists.

3 Technical description of the mission

3.1 Payload concept and mission requirements

The programme would make extensive use of the Ariane ASAP launch opportunity. This can place 50kg spacecraft into GTO or LEO type orbits from an Ariane 4 and it is anticipated that the same facility on Ariane 5 will place 100kg spacecraft into orbit.

The actual deployment of spacecraft will depend on the opportunities available but the target would be to have three or four spacecraft in 12hour geosynchronous elliptical orbits (500km altitude perigee x 7.2Re apogee approximately) at different local times and one in a low-altitude circular, polar orbit. Such launch opportunities are likely to be readily available.

The three spacecraft in (GTO) should have a 12 hour period. This implies that once the satellites are on station they can all be contacted once a day, by the same non-tracking ground station. This could be a modest sized dish at the P.I.institution. There should be 50 Mbits of on-board memory for data storage which would be transmitted to the ground station at around 30 Kbits/s.

The spacecraft should be spinning with sun-pointing axes. A magnetotorquer, a magnetometer and a sun-sensor would be enough to maintain attitude.

3.2 Instrumentation

Instruments The most important measurements are 1. the energy spectrum and pitch angle distribution of electrons from 20keV to 10MeV. 2. the spectrum, pitch angle distribution and mass spectrum of ions up to 50 MeV/q

The techniques to be used will include solid-state detectors in coincidence telescopes, scintillation counters, with pulse height, magnetic or time of flight analysis. There is scope for innovative development of such instruments to reduce the mass and improve the background rejection. Second priority instruments include low energy plasma analysers and wave detectors.

3.3 Spacecraft bus

In order to provide an explicit summary of the characteristics of a suitable spacecraft bus we present the following draft specification.

1. Spacecraft mass 50-100kgs payload mass 10-20kgs
2. Instrument power up to 20 watts
3. Spin stabilised, spin axis towards sun within 5°, spin rate 2rpm
4. Onboard data storage 50Mbit solid state memory → gewicht! SPICA SME oi (w
5. Downlink rate 30kbps
6. Experiment commanding; not more than 10,
   ally none.
7. Attitude control by magnetorquer; attitude measurement by magnetometer and sun sensor
8. Orbit: type a) 12 hour geosynchronous, near-equatorial type b) 400-1000km altitude circular, polar
9. Small propulsion unit for orbit adjust and synchronisation
10. Onboard GPS system for positional information to remove the need for tracking.

Informal discussions with the University of Surrey Centre for Satellite Engineering (USCERS) Research revealed that most of the above requirements are met or exceeded by existing, flight-proven designs. The remainder are within the scope of a modest development. There is also scope to develop the bus capabilities as the programme develops.

3.4 Science Operations

As with the operation of UoSat spacecraft, it is proposed that all operations would be carried out within the research group providing the instrument. They would collect the data, including onboard positional information and attitude measurement direct on to the computers which will perform the analysis. ~~Thus operational support by ESA would not be required~~.

The data would be archived at the PI science laboratory and would be required to be maintained as a data set accessible by the community and with a user-friendly interface. It is intended that the data should be useable as rapidly as possible and

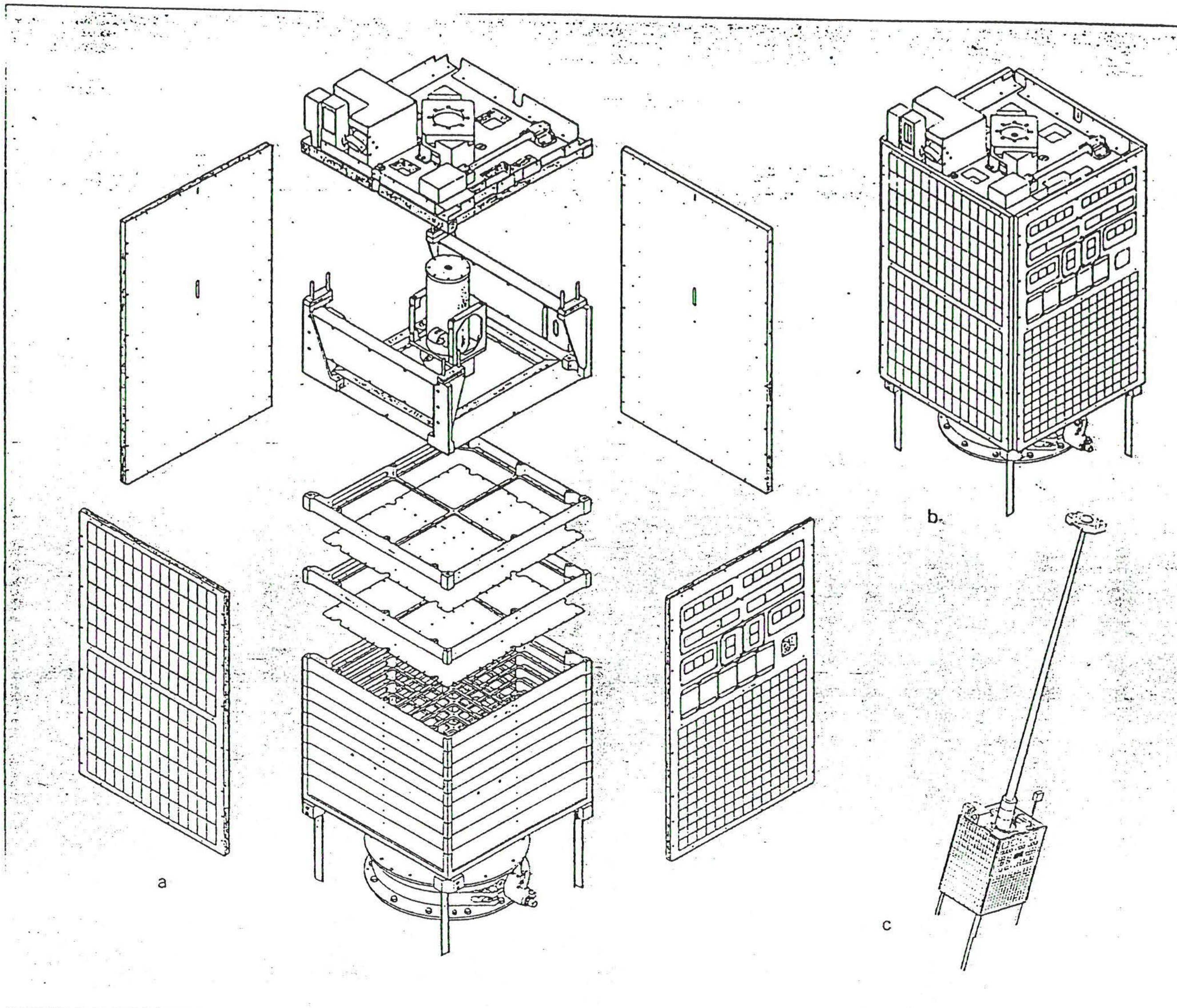

Figure 3

An exploded, assembled and orbital configuration views of the UoSAT 5 microsatellite already built and flown by the University of Surrey, UK. The total weight is 50kgs and the dimensions are approximately a 400mm cube. Such a microsatellite could be used for the programme we envisage here although we propose spin-stabilisation rather than the gravity gradient stabilisation employed by UoSAT 5.

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these data be fed back to the Universities and institutes to stimulate such research. The Belgian Institute for Space Aeronomy would also archive and analyse the data collected. ~~The institute has~~ gained experience in modelling the Earth's radiation belt and in the ~~theory of~~ magnetospheric processes. ~~The *Diensten voor Programmatie van Wetenschapsbeleid / Services de Programmation de la Politique Scientifique* have been informed of this aspect and have received a copy of this proposal.~~

4 Management and funding

Based on costs of previous microsatellites the cost per satellite would be of the order of 2 to 3 mau. Thus a programme scaled at approximately 5 mau per year would allow 2 launches per year and 10 over the initial period of 5 years. This level enables a substantial scientific programme, involving long term, multipoint measurements and the development of innovative instruments and spacecraft techniques to be maintained.

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