Abstract. Synthesizing multi-point in situ observations from the magnetosphere is the only way that we can retain an accurate knowledge of the driving mechanisms of convection and energy flow while "imaging" its vast volume. In addition to measuring the wavenumber of plasma instabilities thus opening up for study a previously unexplored domain of plasma physics the mission can afford us a view of the rapid topological reconfigurations and the energy circulation throughout the auroral plasma regions closest to human space activity. In this paper we argue that the deployment of ~80 autonomous micro-satellites (probes) to monitor the Earth’s magnetosphere and measure the plasma and magnetic field in the near-equatorial magnetosphere is necessary and sufficient condition for answering long-standing high priority questions regarding magnetospheric stability and dynamics. The proposed mission concepts is technically feasible and fiscally modest. The probes can be launched from a Geosynchronous Transfer orbit to their final elliptical orbits with perigee ~3 R_E and apo-
ges ranging from 12 to 4 R_E by a single dispenser propelled by an ion engine. Each probe will weight ~5 kg. The mission can form a cornerstone of an incrementally deployed Solar Terrestrial Probe Line Magnetospheric Constellation, as it requires no new technologies in the areas of spacecraft subsystems and instruments, but some development in the areas of dispenser design, probe packaging, mechanical release and spin-up. The technology developed can be utilized by fol-
low-on Constellation class missions as well.

1. Introduction

The long term correlation between isolated measurements in sepa-
rare geophysical regions (the solar wind, the magnetotail, the iono-
sphere, and the polar cap) will be obtained by ISTP putting to text on
gross spatial and temporal scales our current theories and models of
magnetospheric evolution. As we arrive at deeper levels of understand-
ing of each geophysical region, we realize that spatial-temporal am-
bitious ride our interpretations of single-point measurements from
that region. Simultaneous fortuitous spacecraft co-occurrences within
the same magnetospheric region exist in the ISTP era, but those are
limited to, at most, three spacecraft at a time and have inter-spacecraft
separations that are not optimal for single region studies. Consequently,
ISTP spacecraft are also subject to the interplanetary ambiguities com-
mon to single-spacecraft missions.

The ESA NASA, SCU/CLUSTER and the Solar Terrestrial Probes
mission Magnetospheric Multiscale (MMS) on the other hand, will pro-
vide us with some improved perspective of the microphysics of magneto-
ospheric phenomena. They promise to measure simultaneously and
effective spatial-temporal ambiguities around a localized part of each
region. They are primarily designed to study sharp boundaries and thus
their inter-satellite separation will not exceed ~2 R_E

Approved missions to globally monitor the magnetosphere are IM-
AGE and TWINS. Imaging the immense magnetospheric plasma with cur-
rent energetic neutral atom or other imaging techniques is not possible
at the short time scales of approximately a minute during which the
mission reconfigures. Thus, although IMAGE and TWINS will pro-
vide unprecedented information at the day side magnetosphere and the
near-Earth environment, similar information from the magnetotail will
be lacking. Yet, it is in the magnetotail where the solar wind en-
ergy transfers into kinetic and thermal plasma energy that then af-
fecrs the near-Earth environment. The multi-point study of that energy
transformation and the associated configurational changes in the mag-
netosphere are primary goals of space physics today (Angelopoulos and
space v., 1998). Although our ultimate goal is to position the entire
magnetospheric system in a science-driven fashion, our approach in
this paper will be to start by identifying the most essential questions
that need to be answered in the field of magnetospheric research, per-
form a feasibility analysis of a strawman mission concept, and pin-
point the elements that render this minimal mission possible.

2. Zero Level Science Goals

Of all the questions in magnetospheric physics, not accom-
plished the historical evolution of the field over the last 30 years, yet still
remains largely unresolved. That of conversion of magnetic to plasma
kinetic and thermal energy during the course of magnetospheric
substorms and the associated magnetospheric reconfiguration. Knowl-
edge accumulated to date strongly indicates that the difficulty lies in
the localization of the phenomena both in space (to scale sizes of 1-2
R_E) and in time (1-2 minutes) despite their large-scale consequences
over longer time scales. A single spacecraft within the vast magneto-
ospheric system has little chance of being at the key regions at the time
of substorm onset. More importantly, the lack of simultaneous mea-
surements from adjacent "pixels" of the system prohibits us from plac-
ing the observed phenomenon in the context of the global magnetospheric
evolution. In the following, we present the zero level questions and
document the necessity for a multi-probe investigation of the
magnetotail.

2.1 Substorm Chronology

Substorms are defined on the basis of their ionospheric signatures
(Akasofu et al., 1980) but they have reproducible near-Earth magneto-
ospheric signatures. These are: the energization of particles at geo-

chronous altitude and the elevation increase of the magnetic field in
the near-Earth nightside magnetosphere (McPherron et al., 1991).
Contrary to the ionosphere, where a global picture can be obtained
with all-sky cameras, radars, and magnetometer network, in space we
depend on statistical analyses to compose a time history of events. Such
analyses and a few fortuitous two- or three-spacecraft conjunctions,
we have learned that the field dipolarization starts at a localized region
of the order of 1-2 R_E (Ohtani et al., 1992) and propagates longitudi-
nally (Nogar, 1982) at a speed of an hour of local time every 1-3 min-
utes and radially outward (Jacques et al., 1993) with a speed of ~200
km/s, or 2-3 H, days. Tailward flows are observed during substorms,

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most often at distances greater than 1R_s while Earthward flows are observed closer to Earth [Antropov and Haidas, 1994]. These flows have been interpreted as signatures of magnetic reconnection. The reconnection site also moves downward during the course of a substorm [Seybert et al., 1993] as speed comparable to the speed of the current disturbance.

The time and location of the first magnetospheric signature of substorm onset and its relationship with the ground observables still remains a mystery. For example, Baker and McPherron [1990] sug-
ggest this as the basis of the near-Earth neutral line model, that tailward flows should start before ground substorm onset. However, Lui [1996] suggests on the basis of the current disruption model that tailward flows are the consequence of near-Earth current disruption and thus-reconnection should then start after substorm expansion phase onset. The "strong version" of the Kunita conjecture [Kurita, 1992] has been that not only this remains an open question but that there is also the possibility that the two phenomena are totally uncorrelated. The resolu-
tion of this issue requires sufficient (less than 1 minute, the Alfvén bounce time) temporal resolution and sufficient (~1-3R_s, the scale size of the initial active region) spatial sheet coverage on the X-Y plane.

The maximum altitude of spacecraft necessary to capture the reconnection process is determined from recent GEOTAIL results, which place the most likely position of the near-Earth neutral line around X~20-30R_s [Nagasato et al., 1997]. Many times of spacecraft at cross-tail separations ranging between 1 and 20R_s and at downtail positions between 7u to 40R_s, are sufficient conditions for the study of the magnetospheric evolution during the course of a substorm. Quantitative necessary and sufficient are time resolved (~1-5) magnetic field and 3D ion motion measurements.

2.2 Substorm Current, Energy and Magnetic Flux Budgets

Substorms are the primary mechanism of energization of the night-
side ionosphere and ring-current. Modelling of the geomagnetic in-
jections during substorms as fronts of Earthward-collapsing particles [Mauk, 1986] issued on measured electric fields observed in the near-Earth jovian sheet [Aasen et al., 1983; Maynard et al., 1992] has provided fairly good agreement between theory and observations [Quinn and Southwood, 1982]. In this scenario it is the breaking of the Earthward flows [Sashikawa et al., 1998] resulting from either the current disruption or the reconnection process that causes the near-Earth signatures of substorms. In the magentotail of X~15R_s and close to the neutral sheet, fast plasma sheet flows are responsible for most of the plasma sheet energy, particle and flux transport [Angelopoulos, 1994]. Such flows are most often observed within 3Y_s 3R_s from the mid-plane axis [Bastian et al., 1993]. Are the last flows that are observed at substorm onset of sufficient energy to ac-
count for substorm energization of the near-Earth environment and the ionosphere? The answer depends on the 3D evolution of the magnetospheric flows. Given the extreme localization in Y of some of the fast flow events observed so far, sufficient simultaneous multi-point measure-
ments over an extent of 340-10Y_s and at a probe density of 1 mea-
surement per 1-3R_s in Y are necessary.

The longitudinal spread of the substorm current wedge (SCW) is coupled to the westward travelling surge in the ionosphere [Rosen et al., 1991; Kivelson et al., 1984; Maynard et al., 1994]. The extent of Y of the SCW at distances far from geosynchronous is neither known, nor possible to document with single spacecraft because it is a three di-
ensional system. Lopez and Lui [1990] used AMPTE/IRM and CCE observations to show that the SCW is irregular in space. Moreover, substorms typically manifest themselves in a series of convoluted, iso-
lated activations. The near-Earth and ground signatures are the inte-
gred response to multiple localized acceleration sites. Such individual activations are possibly the elemental processes comprising substorms [Seybert et al., 1986]. Multi-spacecraft observations will result in re-
solving the ambiguities associated with the number, location and ex-
tent of such activations. Understanding the three-dimensional evolu-
tion of the substorm current wedge promises to shed light on the magnetosphere-ionosphere energy coupling during a substorm.

2.3 Current Sheet Thickness and Evolution

Present attempts at addressing the substorm onset question on the basis of current sheet instabilities require direct measurements of the current sheet thickness and intensity [Lui, 1996]. Attempts to model the current sheet thickness and density by inverting the observed magnetic field measured at more than one location during different conjugation of spacecraft has lead to considerable success [Pollock et al., 1991]. In addition, inversion techniques in the tail using two spacecraft [McComas et al., 1990] have given incontrovertible evi-
dence of the existence of the current sheets and their importance dur-
ing substorms [Liu et al., 1991]. However, the only possible way to ensure that the ion current system is adequately monitored at the time and place where it actually becomes unstable is to simultaneously monitor its thickness at many different distances. This neces-
sitates a CLUSTER-like system at many different distances. One way to achieve this is to provide some orbits with enough separations in X~1-2R_s at different downtail distances. For current sheet densities of the order of 1 nA/m² which are typical of the cross tail current, and inter-circular separations of 1R_s such measurements can be made com-
fortably with 0.5 nA accuracy i.e. well within the capabilities of con-
ventional magnetometer designs. Vertical separations of the order of 1 R_s are necessary in order to bracket the ion and often variable-scale size cross tail current but also sufficient for such observations.

2.4 Modeling and Variability of Magnetospheric Currents

Global magnetospheric models, with the exception of global MHD are static [Tsunoda, 1995]. The large magnetic field variability in the databases that are used as input to these models [Stern and Tuominen, 1992] suggest that a significant part of the physics that determines the most probable magnetospheric state is missed. Most often, severe modification of the model currents is necessary away from expected state [i.e., for the measured Kp or AE parameter] when actual time-dependent situations are considered [Pollock, 1991]. It is impossible for a static model parameterized on global indices to cap-
ture the complexity, the richness and the physics of the instantaneous magnetospheric configuration. However, a large array of measurements from magnetospheric probes can produce, when inverted using tech-
niques available from statistical [Tsunoda and Uman, 1982], simulation [Berchem et al., 1993] and artificial [Ghil and Malanotte-Rizzoli, 1991] models, an instantaneous "image" of cur-cents and fields that is consistent with the interplanetary data but represen-tative of the instantaneous measured fields. This can produce a far clearer picture of the current systems' sources, sinks and tempo-
ral evolution.

2.5 Rate of Accelerated Particles

The three-dimensional circulation of the substorm-accelerated par-
ticles is not clearly understood. Huang et al. [1992] have shown that plasma sheet temperature increase after substorm onset represent an important plasma sheet response to geomagnetic activity that does not
always correlate with flow enhancements. Although single particle approaches (Spero and Kivelson, 1993; Spero et al., 1993; Ashour-Abdalla et al., 1994) have led to certain predictive pictures of the plasma sheet proton, temperature, and minority spatial studies, which were yet to be verified observationally. There is a clear need to observe the system and its evolution at many points simultaneously for a given thermodynamic state. This entails fine spatial resolution of observations of the instantaneous flow pattern, density also temperature to observe the source and propagation of the resulting heating. The reason for the fine spatial resolution is twofold. First, the acceleration regions are lo-

2.6 The Most Common State of the Plasma Sheet
Although the most dramatic plasma sheet phenomena occur dur-

2.3 Plasma Sheet Thermodynamics
Attempts to characterize the thermodynamics of the plasma sheet (such as measuring its polytropic index) have been so far inconclusive (Baumjohann and Paschmann, 1989; Huang et al., 1989; Gruzin and Baumjohann, 1991). Room for controversy exists because with single spacecraft we cannot observe the evolution of a single flux tube. Multi-probe studies that utilize two (or more) spacecraft traversing plasma streamlines will be able to answer the above question. How-

3. The Zero Level Mission
3.1 Overview
The zero level science goals can be met with a fleet of 80 low-cost, low-data-rate probes instrumented with a triaxial fluxgate magnetometer and a three-dimensional ion distribution sensor. The probes will be spin stabilized at a period of 3 s. The number of probes was chosen based on a science-driven plasma sheet coverage of 1 probe per ~3 R_E covering the region -10<χ<40 R_E and -5<υ<15 R_E and assuming an equatorial distribution of probes that is randomized due to orbital perturbations. Low data accumulation rates will result in low transmission power requirements at perigee (store-and-dump down- link). Perigee will be between 2.5 and 3.5 R_E to ensure an acceptable transmission rate, adequate visibility from two anti-symmetrically located ground tracking stations and a relatively benign proton radiation envi-

3.2 Orbital Characteristics
The orbits were chosen on the basis of the following requirements: 1) The orbit should have a maximal probability of being inside the plasma sheet, if not at the neutral sheet. Since the distortion of the neutral sheet surface increases with dipole tilt, we demand that the apogees be at midnight at equinox, a period associated with minimal seasonal tilt. 2) The orbit planes should cross the neutral sheet at times when ground magnetometer and radar coverage is maximal, i.e. when the US sector is near midnight (i.e. at 0630 UT). At that time and at vernal equinox the dipole tilt is approximately -10 degrees. 3) The orbits should avoid Earth's shadow for periods longer than 1.5 hours to avoid complex thermal and electrostatic designs. Every 5 R_E in apo-

4. Detrimental purposes the probes were placed at their perigees at the same time (Winter Solstice, 1996) and then were propagated using the Goddard Trajectory Determination System (includes Solar, J2, Lunar and atmospheric perturbations) to their positions 3 months later. Sufficient longitudinal coverage and sufficient probe density is achieved, in accordance with the science requirements. Figure 6 of Delory et al. (1998) shows that the Z-segmented probes are not signifi-

5. Of course due to tracking and instrument failures, the prolonged lifetime should not be
Table 1. SciencePayload and data accumulation

<table>
<thead>
<tr>
<th>INSTRUMENT</th>
<th>Mass (kg)</th>
<th>Power (W)</th>
<th>Data Rate (bits/s)</th>
<th>Data Rate (bits/Orbit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triaxial Flattop Magnetometer</td>
<td>0.6</td>
<td>0.5 W</td>
<td>17 bps</td>
<td>1.0X10^6</td>
</tr>
<tr>
<td>Ion Electrostatic Analyzer: Tophat, 16E X 22.5° FOV, 16 Energies, 3eV - 4keV</td>
<td>1.0</td>
<td>0.75 W</td>
<td>35 bps</td>
<td>2.0X10^6</td>
</tr>
<tr>
<td>Masses</td>
<td>35 bps</td>
<td>30 bps</td>
<td>3.2X10^6</td>
<td></td>
</tr>
<tr>
<td>Burst: 20 min at 6 s.</td>
<td>6.8X10^6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>1.6</td>
<td>1.25 W</td>
<td>30 bps</td>
<td>6.8X10^6</td>
</tr>
</tbody>
</table>

A top-hat ion electrostatic analyzer with a heritage from FAST will perform measurements of ions in the 3 eV - 40 keV range. The configuration has a 180X14 degrees field of view allowing measurement of a full 3D distribution function once per spin. Ions entering the analyzer are selected in energy and imaged onto a micromechanical (MCP) plane at 90 degrees. Using a 20% margin on total power we may power consumption less than 750 mW. Measurements are performed at 16 energy steps with width ∆Ε/E=0.78 and a geometric factor of 4x10^{-1} cm^2·s·eV. Raw data in a full distribution function is 16x10^4 bytes. This is fed to the data processing unit which performs the moment computations. The basic quantities of density, velocity, and pressure tensor give us ~104 bits per measurement.

The probe design is such that cannot afford multiple subsystems bolted on a generic bus. Bus design must be "holistic" i.e., instruments and spacecraft subsystems must be highly integrated (Fig. 2). The probe must be viewed as a single instrument, minimizing connectors, wires and integration and testing. A triangular shape provides minimal spin-ripple of solar input power.

3.3 Instruments

Magnetic field measurements at 1.5 - 5 resolution with spin axis and angle knowledge of ~0.1 degrees, sensitivity to ~0.1 nT and range from 0-20000 nT are required. An orthogonal triad of sensors on a fixed boom (30 cm) is far enough from the spacecraft that does not necessitate an expensive magnetic cleanliness program, especially with an early design and program mitigation program. Wiring of solar cells, battery and instruments are the most important items in such a program, but are quite benign relative to subsystems on traditional spacecraft. The electronic design can be borrowed from that used on the FAST Small Explorer mission with small simplifications for reducing power and weight. The modifications should take advantage of relaxed reliability requirements stemming from redundancy that is built in the numbers of probes rather than in the probe components. The mass of the main electronics is 0.4 kg and the sensor triad plus cabling is 0.1 kg. The electronics unit draws 0.5 W of refined power. By minimizing range changes and using digital filters, the magnetometer is both simple to calibrate on the ground and easy to operate in space. On board spin averaging can be performed with a simple hardware-implemented addition and subtraction operation using the sun pulse as reference at a negligible power cost. The magnetometer boom structure, be it of a telescopic or hinged arm type, weighs less than 100 grams including wiring.

3.4 Data Acquisition

Following the science requirements from the previous section we assume magnetic field and ion moments collected at 3 resolution (1 spin). Routine transmission of ion distributions is necessary every ~5 minutes for ascertaining the validity of the on-board ion moment computations, and studying individual events in detail. Burst mode storage of ion distributions is necessary when most satellites are positioned in the plasma sheet at a high rate (6 s) for a period of ~20 minutes/day. This mode can be routinely performed at times that the expected neutral sheet crossings occur on the basis of a model, upon ground commands, or upon an on-board detection of an "active" plasma sheet encounter. The total data budget for the mission is shown in Table 1. A total of 68 Mbits will be stored in the highest apogee orbit, (6.5 days) including burst mode data. Data compression can further reduce the total amount of data significantly allowing either higher sampling rates or increased burst time.

3.5 Data Storage

Data storage requires a maximum of 80 solid state memory chips (SRAM, 1 Mbit each) at a total of 160 gigabytes including a hardware-
3.6 Data Transmission

Data transmission can be achieved at or near pejoric (3 R, perigee, or ~1000 km minimum range). Assuming contacts from a range of 20,000 km on or less, an omnidirectional transmitter in the S-band (2.3 GHz) with radiated power of 2 watts, and a 10 m diameter ground station, we can achieve a downlink rate of 200 kbps, with link margin better than 3 dB (see Angelopoulou et al., 1998 for the details of the link computation). The telemetry system envisioned comprises a body-mounted whip 4/8 wave antenna. The antenna gain pattern is subject to diffraction and is quite anisotropic (Scharf et al., 1998). The total attenuates weight is approximately 0.19 kg. The transmitter can operate at 28.8 V voltage and is 9.8A maximum current with 2 Watt output power. Even in the absence of the data compression the total data required for data transmission is around 2.5 minutes. This requires a total energy of ~2.5 Wh which has to be supplied by the battery. The commercial receiver envisioned operates using the same antenna in a slightly different frequency. There is no maximum for two-way telecommunications, which makes for a simple RF system on-board.

3.7 Power

Powering transmitters with a nominal 10% efficiency using conventional Cadmium batteries would be exceedingly heavy for the mission. We sought alternative solutions in Li-Metal (LMB) battery technologies, which are driven by the cell's thermodynamic, as well as rechargeable properties. The most suitable candidate is the Li-Metal-Activated NiMh (LMA-NiMh) battery, which has a high energy density and a low recharge rate, thereby allowing for a shorter charge time. The LMA-NiMh battery has a nominal capacity of 0.73 Wh. This gives us a total of ~3 Wh. Operating at 0.8 A/m for nominal transmitter operation, we can transmit 3.9 W per 6.5 minutes. This allows for a lifetime of 3000 days, i.e. much longer than the mission lifetime. An alternative scenario that doubles the power to 8.0 W has provided two identical 2-sided battery packs for redundancy. Usage of NiMh battery technology (LMA-NiMh) can result in similar power system capabilities.

The batteries are powered by solar cells. We can use flat panels of 6 inch side, made up of 2 cm X 2 cm size GaAs cells. Each panel can produce at the end of mission 1 (1 year duration) a power of 3.2 Watts and 32.5 Volts, in the fluxes experienced in the lowest (heaviest radiation) orbit. With 6 m/s of overcast used in the energy, the power generated is 0.063 Wh. However, the LMA-NiMh batteries can provide a backup option during the mission.

Figure 2: Payload layout.

above comparison, 19% of the solar cell weight is in the coating, 40% is in the cell itself and the remainder of the weight is in the adhesive, wires and other circuitry. Each panel weighs 38.4 grams. A nearly constant power of 3.2 Watts is thus produced during a spin. The end-of-mission characteristics satisfy the power needs of 2.384 W at a weight (3 panels) of 0.115 kg. The panels should be mounted on a graphite epoxy substrate of thickness 0.5 mm weighing less than 72 grams, including mounting posts and spacecraft body.

3.8 Tracking

Assuming a random set of orbits with perigee at 20,000 km and apogee ranging from 12 to 42 R, how many can we track within a given period of 45 days? The results are shown in Figure 11 of Angelopoulou et al. (1998) shows a set of plots that include the case of tracking of 40 probes and states that the probe must be tracked for at least 2 days. This is essentially a ground station tracking system for an arbitrary 3-day period in the life of the mission. A successful probe contact constitutes a 30 min tracking opportunity (probe velocity 10 degrees above the horizon) for the purposes of that event. The extra time above 6 m minutes of contact time is allocated for ensuring troubleshooting in cases of problems, but is not allocated routinely. A 10 minute tracking window is assumed for cost estimation purposes. With a simple station we are able to track 75% of the probes. Probes that are not tracked by the UC Berkeley station were predominantly those that did not make ground contact over the 6.5-day period, not ones lost due to schedule conflicts.
3.9 Ground Operations

Simple probes do not necessitate complex ground operations. Ground stations automation as it is currently applied on Small Explorer missions can drastically reduce mission operations costs far below the current norm of $60000/contact. Some aspects of the ground operations are outlined in Angelopoulos et al. (1998).

3.10 Attitude and Orbit Determination

The ACS requirements are quite simple. Only attitude knowledge to within ±5 degrees is required. This attitude knowledge can be achieved from a combination of two sun sensors and a V-shaped tach and an infrared detector for Earth and Moon detection. Error analysis of typical, low cost, lightweight sensor data results in a 3-sigma error of less than 0.5 degrees.

Orbital determination to better than 600 km at apogee is the science requirement. This results in interprobes separation knowledge to within 10% or better. This can be easily achieved from ground station angles obtained from tracking. The orbit solution converges. Given the long (2 month) period that intervenes between the probe egress and the commencement of the primary science phase of the mission, there is adequate time for solution convergence of all orbits, including the highest apogee ones.

3.11 Probe Mass and Power Summary

Table 2 presents the mass and power estimates of the proposed probe design. In addition to the power estimates described in the individual sections above, we note the following: the command receiver will be powered off in the interplanetary phase but in the event of a

Table 3. Launch feasibility

<table>
<thead>
<tr>
<th>ITEM</th>
<th>WEIGHT (Includes 30% Margin)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spacecraft (80)</td>
<td>409 kg</td>
</tr>
<tr>
<td>Dispenser</td>
<td>151 kg</td>
</tr>
<tr>
<td>Total launch capability</td>
<td>561 kg</td>
</tr>
<tr>
<td>Torus (XL-4213) delivers to GTO</td>
<td>393.3 kg</td>
</tr>
<tr>
<td>Fuselage</td>
<td>33 kg + 18 (Total - Margin)</td>
</tr>
</tbody>
</table>

4. Orbit Attainability

Our working hypothesis is a fully autonomous deployer (probe disposer) that can release and fly up each probe in its ascendant to the final orbit. Each probe can be released and flown up by a dispenser-mounted spring. A tentative relative-nutation has been studied for a pathfinder mission by Lee et al. (1998). Probes to be separated in Z at apogee should be released at the mean anomaly where their
5. Preliminary Cost Estimate

The probe cost estimate is performed on a component-by-component basis. No cost model available was adequate for the probe envisioned because the integration possible for the simple probes envisioned has no equivalence in traditional spacecraft designs. The development cost is a small fraction of the total mission cost.

The bulk of the mission cost is primarily on parts procurement, assembly and testing, which is performed in a traditional fashion. In-flight testing costs can be reduced through careful unit design, and by the use of an automated testing facility (such facilities already exist for magnetometers at UCLA and for plasma instruments at UC Berkeley but also at other institutions). The ion engine price is based on the NSTAR cost estimate. The solar panel price reflects the cost of the SCARLET II array developed by ASE-ABLE Engineering, Inc. quoted by that company. The probe dispenser cost is based on a UC Berkeley mechanical design and an experience from consultants from the defense industry who have built multi-probe dispensers before. This includes the integration of the probes and the ion engine on a stack that meets the fairing specifications of the launch vehicle. Ground operations are based on HESSI and FAST experience. They assume free use of the 11 meter diameter NASA tracking station recently procured for HESSI and installed at the UC Berkeley campus. A person-month cost is $10K in all of the above estimates. The total mission cost, including launch vehicle, and assuming a 30% contingency is $125M, which classifies it in the NIDEX category (capped at $140M).

6. Data Visualization and Reduction

The proposed mission transmits traditional data analysis operations associated with single spacecraft. Visualization of multipoint datasets from many different points in space will be necessary. Inversion techniques to fit, purely sampled data to a prescribed magnetospheric model are important. These types of data products should be distributed. 1) Synoptic, three dimensional images of extraterrestrial pressure, magnetic field strength and plasma flow profiles will give a first look at the dataset (Figure 3). The first generation of operational magnetospheric models to be used for magnetic field inversion can be the Tyaganenko [1995] model that requires Solar Wind and Dst input and has specified magnetopause currents. The output should be a time-dependent 3-D model parameterized not to fit the AE index as is now the case, but the probe data instead. The location of the probes superimposed in the images when provided to the community will give instantaneous information on magnetospheric conditions but also on data availability and the extent to which the synoptic images are restricted by measurements. 2) A three-dimensional walk through space in a “Virtual Reality” fashion is possible. Much like the HTML language which has recently revolutionized data exchange and communications of two-dimensional information, the VRML language is now on the verge of revolutionizing the exchange of three-dimensional images (http://www.w3d.com/). Selection of a probe in a hypertext fashion will open up a separate window with time series overview information on a simple probe. The user can then request the data from that period, plot the data locally or click on another probe to intercompare data from two points. Raw data will be sent to the user upon request in a format designed by the CDFM facility. The user will be able to

Figure 3. The reconstructed equatorial energy flux density and global magnetic field during the time of a plasmoid formation and its downtail ejection. Probes were run through an MMS simulation of the magnetosphere and the measured parameters were used to reconstruct the equatorial energy flux density. Mapping images and distribution functions along reconstructed model drift lines can produce information within a large volume of the tail.