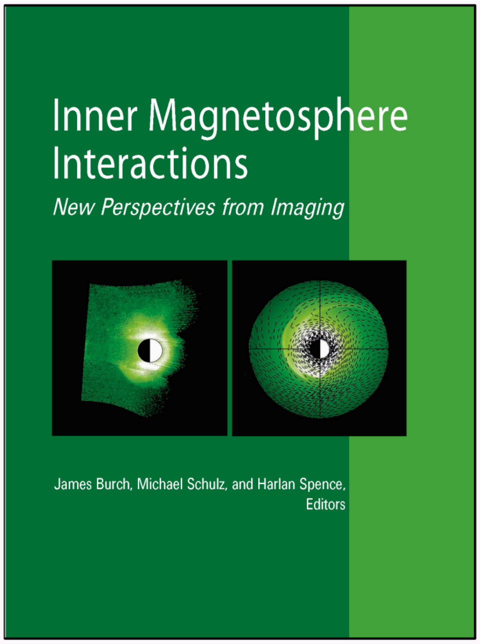

Imager for Magnetopause-to-Aurora Global Exploration (IMAGE)

Senior Review 2005

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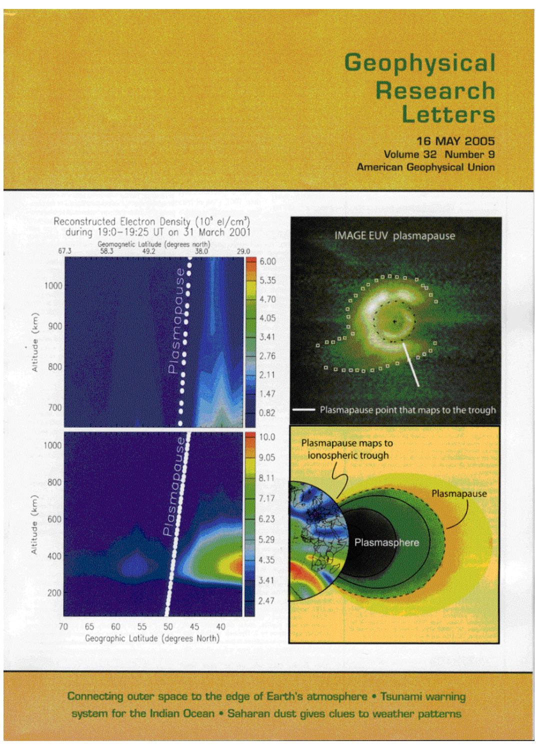

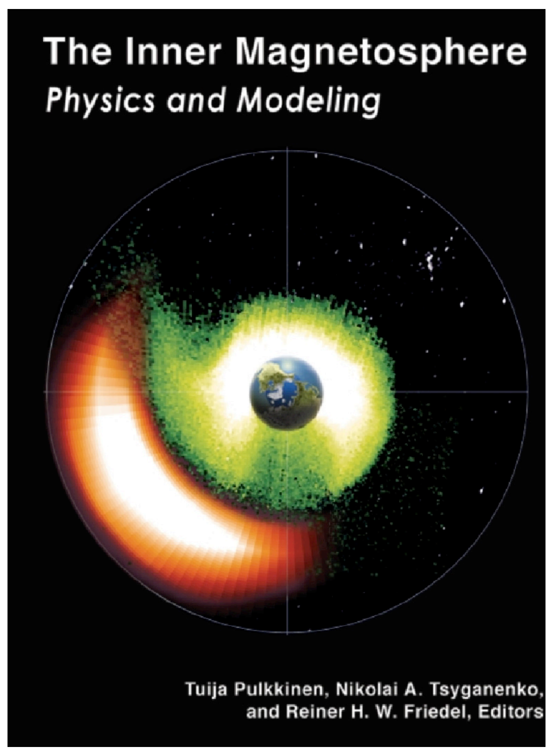

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Executive Summary

The Imager for Magnetopause-to-Aurora Global Exploration (IMAGE) mission continues to be an extremely productive component of the Sun-Solar System Connections (S³C) Great Observatory. As the first satellite dedicated to imaging Earth's inner magnetosphere, IMAGE has opened a new era in our understanding of the magnetosphere and its constituent plasma populations as a highly coupled global system.

Accomplishments. During its first five years of operation [*Burch,* 2005], IMAGE has a) confirmed several theoretical predictions (e.g., plasmasphere plumes, pre-midnight ring-current injection, and continuous antiparallel reconnection), b) discovered numerous new and unanticipated phenomena (e.g., plasmasphere shoulders, subauroral proton arcs, and a secondary interstellar neutral atom stream), and c) answered a significant set of outstanding questions (e.g., regarding the source region of kilometric continuum radiation, the role of solar-wind pressure pulses in ionospheric outflow, and the relationship between proton and electron auroras during substorms). In addition to studies based exclusively or primarily on IMAGE data, IMAGE observations continue to be used in conjunction with data from other spacebased and groundbased assets in numerous collaborative investigations both by the IMAGE team and by other members of the space physics community. IMAGE-related investigations accounted for 19% (12/64) of the Guest Investigations awarded in 2004 and for 33% (11/33) of those awarded in 2003.

Among NASA's space physics missions, IMAGE has received a noteworthy level of media coverage (**Figure 1**). IMAGE's dramatic images and movies of Earth's magnetosphere in action have enabled the general public to visualize our space environment and to appreciate the impact of space weather to an extent not possible in the era before global imaging.

Extended Mission: 2007-2010. During the period 2007-2010, IMAGE will be the primary tool for global auroral and inner magnetospheric imaging within the S³C Great Observatory. Collaborative research with other S³C missions such as Cluster and TWINS as well as IMAGE-only investigations will play an important role in addressing research objectives set forth in the 2005 S³C Roadmap. IMAGE science investigations proposed for this phase of the mission fall into five broad thematic areas: (1) Reconnection; (2) Electrodynamic Coupling; (3) Plasma Injection, Transport and Loss; (4) Hot-Cold Plasma Interactions; and (5) Remote Sensing of the Heliosphere. The IMAGE extended mission will occur at solar minimum and during the ascending phase of solar cycle 24, allowing study of the inner magnetosphere near its "ground state" and of its response to isolated storms. The data acquired during this phase of the mission, together with the data from the maximum and declining phases of solar cycle 23, will enable comprehensive understanding of the global structure and dynamics of the coupled magnetosphere-ionosphere-thermosphere system at all levels of solar activity. The evolution of the IMAGE orbit between 2007 and 2010 will allow sustained viewing from low, middle, and high latitudes.

Status of the IMAGE Mission. Each of the six IMAGE instruments has contributed significantly to the mission's scientific success, in no small part because of the integrated nature of the payload and the resulting data stream, which uses a common format that facilitates the joint plotting of data. The IMAGE spacecraft and all instruments are operating very well, and there is every expectation that they will continue to do so for many more years. The precession of apogee to the southern hemisphere has not affected operations in the baseline store-and-forward data transmission mode. For reception of real-time data, which are transmitted continuously for space forecasting purposes as well as for backing up occasional data loss in the store-and-forward mode, a southern-hemisphere receiving station has been established at the University of South Australia.

IMAGE Data System. IMAGE data can be accessed from centralized web sites/servers at GSFC (both at the IMAGE Science and Mission Operations Center (SMOC) and the National Space Science Data Center (NSSDC)), as well as through web sites maintained by the individual instrument groups. Level-1 data are available from the SMOC within 24 hours of their receipt from the Deep Space Network (DSN). Level-1 data include CDF files and GIF images from all instruments at their full time resolution but with a limited set of wavelengths, energies, and species. The full data sets are available within three days in the Universal Data Format (UDF) [*Gurgiolo*, 2000]. The software needed to acquire, plot, and analyze UDF data is available for free download from several sites and for all the major platforms (UNIX, Windows, Mac OS-X). The IMAGE team expects to participate and contribute to the emerging S^{3}C distributed data environment. In particular, we will work with a Virtual Magnetospheric Observatory if it is approved as part of the current "VO" call for proposals, and with other ongoing efforts such as the Virtual Space Physics Observatory as these systems are established.

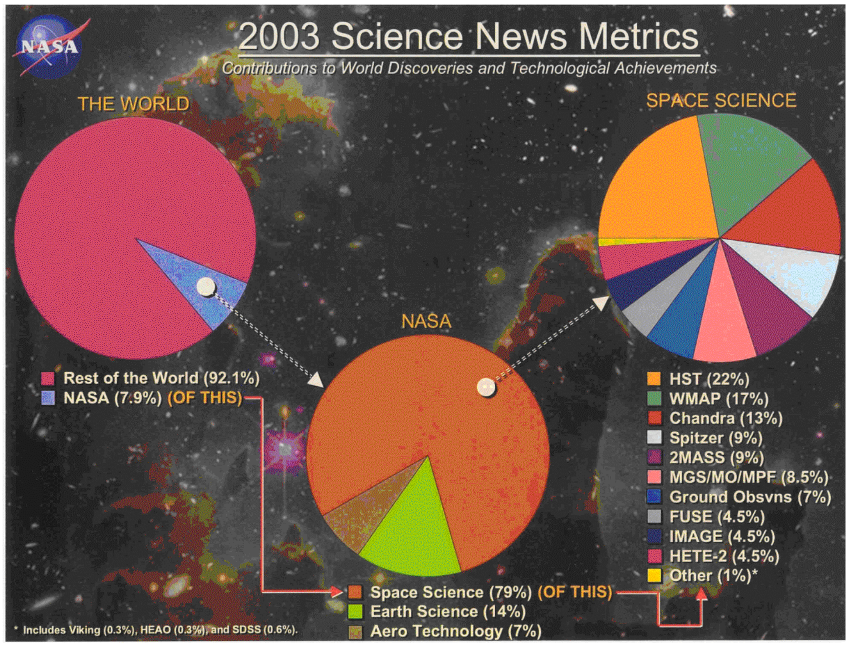


Figure 1. Statistics from Science News in 2003 compiled by Greg Davidson, an independent consultant for OSS (now Science Mission Directorate) show that IMAGE ranked 9th among all OSS missions in stories on contributions to world discoveries and technological achievements. IMAGE was the only S^{3}C mission in the top ten.

Education and Public Outreach. The IMAGE E/PO program, called POETRY (Public Outreach, Education, Teaching and Reaching Youth) was implemented several years before launch and is well integrated into the Sun-Earth Connections Education Forum. It has received national recognition and awards for books, curricula (primary through secondary), teacher training events, interactive web site, museum kiosks, educational video, and planetarium exhibits. During the extended mission, the IMAGE POETRY program continues to produce high-quality and innovative education products that explain space physics concepts to teachers and students in the K-12 community and the public.

IMAGE Publications and Presentations. Since the launch of IMAGE on March 25, 2000, 341 peer-reviewed papers using IMAGE data or describing IMAGE instrumentation have been published or accepted for publication or are in review. Since the last Senior Review, in May 2003, 203 new papers have been written. About half of all IMAGE papers have first authors who are not members of the original IMAGE team. In addition, about half of all IMAGE papers used data from the S^{3}C Great Observatory missions, ground-based data, and other missions. Most recently, in 2005, that percentage exceeds 62%. At the current rate we expect to have twice the number of papers published in 2005 as we did in 2004. **Table 1** summarizes the IMAGE publication record by instrument from launch till the present. In each case, either the primary data source or the affiliation of the first author was used to classify the paper. Papers listed under "all" involve the entire IMAGE payload. Also shown in **Table 1** is the percentage of papers using data from other observatories

Table 1. Number of IMAGE papers by year and instrument. "All" refers to papers using data from all IMAGE instruments. "% Other Data" shows percentage of papers using data from ground-based and other space-based sources, including S^{3}C Great Observatory missions.

	FUV	EUV	HENA	MENA	LENA	RPI	All	Total	% Other Data
All Years	114	45	41	22	34	66	19	341	48
2005	41	16	18	7	10	22	5	119	63
2004	20	11	9	3	7	17	0	67	53
2003	26	10	4	4	7	11	2	64	45
2002	14	5	4	2	1	4	3	33	45
2001	8	2	4	2	4	5	3	28	30
2000	5	1	2	4	5	7	6	30	0

and missions, including S^3C Great Observatory missions. In addition to published papers, 20 PhD theses have been written using IMAGE data. These statistics—the numbers of published papers and the numbers of theses—clearly document the productivity and vitality of the IMAGE mission.

An on-line bibliography of IMAGE publications can be found at http://image.gsfc.nasa.gov/publication/.

I. Introduction

IMAGE is the first satellite mission dedicated to imaging Earth's magnetosphere. Its overall science objective is to determine, through a combination of global magnetospheric and auroral imaging (**Table 2**), how the magnetosphere responds to changing conditions in the solar wind. ***During the spacecraft's 5.5 years of operation, IMAGE results have led to major advances in our knowledge and understanding of 1) the dominant mechanisms for injecting plasma into the magnetosphere on substorm and magnetic storm time scales; 2) the magnetosphere's directly driven response to the solar wind; and 3) the energization, transport, and loss of magnetospheric plasmas during storms and substorms***. IMAGE observations have revealed unexpected new phenomena, provided evidence that confirms theoretical predictions, allowed researchers to test and refine hypotheses, and improved our understanding of the geospace environment [*Burch et al*., 2001a; *Burch*, 2005]. **Table 3** illustrates schematically the progression from "initial discovery or confirmation of prediction" through "explanation or hypothesis testing" to the eventual "understanding or application" for nineteen IMAGE science investigations. These advances in our knowledge and understanding of the geospace environment would simply not have been possible without global imaging and are illustrative of the continuing vitality of the IMAGE mission.

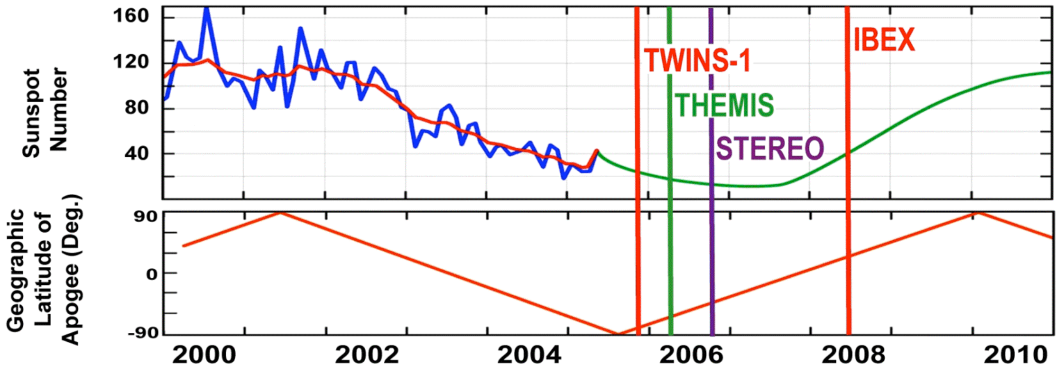
Many of the scientific results obtained by IMAGE have benefited greatly from correlative measurements made by other NASA S^3C missions as well as from non-NASA assets such as the DMSP and LANL spacecraft. By the same token, several of these same missions have been aided in their in situ investigations by the contextual information provided by the global imaging capability of IMAGE. ***This crossfertilization between global imaging and in situ measurement has been enormously productive and demonstrates the vital role that IMAGE plays within the Great Observatory as NASA's primary tool for global magnetospheric and auroral imaging.***

IMAGE's global, systems-level view will continue to be needed during the period 2007-2010 as new Great Observatory missions are launched, bringing new measurement capabilities to bear on the Sun-Earth system, and as currently operating missions continue to produce data whose scientific impact is significantly increased by the availability of global contextual information. IMAGE observations can help guarantee the success of other S^3C investigations by 1) helping them to achieve their scientific goals earlier in the mission (e.g., stereo imaging with TWINS-1 prior to the launch of TWINS-2), thus reducing their closure risk; 2) providing the contextual information that eliminates spatial-temporal ambiguities found in more local measurements and that ties together all available S^3C observations into a single coherent picture; and 3) supplying key quantitative global image products (see **Section III**) that are critical to S^3C science goals and that cannot be obtained in any other way. Continued

Table 2. The IMAGE science instruments.

Imager	Objectives	Measurements
Low-Energy Neutral Atom (LENA) T.E. Moore (NASA/GSFC)	Image ionospheric outflow	Neutral atom composition and flux at 10 eV to 1 keV with field of view of 90° x 360°, angular resolution of 8°, and energy resolution of 80%
Medium-Energy Neutral Atom (MENA) C. J. Pollock (SwRI)	Image inner region of plasma sheet	Neutral atom composition and flux at 1 keV to 50 keV with field of view of 90° x 120°, angular resolution of 8°, and energy resolution of 80%
High-Energy Neutral Atom (HENA) D. G. Mitchell (APL)	Image ring current	Neutral atom composition and flux at 20 keV to 500 keV with field of view of 90° x 107°, angular resolution of 8°, and energy resolution of 80%
Extreme Ultraviolet (EUV) B.R. Sandel (U. Arizona)	Image plasmasphere	Extreme ultraviolet irradiance at 30.4 nm with field of view of 90° x 90° and angular resolution of 0.6°
Far Ultraviolet (FUV) S. B. Mende (UC Berkeley)	Image electron and proton aurora; map geocorona	Far ultraviolet irradiance at 135.6 nm, 121.8 nm, and 140-190 nm with field of view of 17° and angular resolution of 0.1°; geocorona maps with three 1° field-of-view photometers
Radio Plasma Imager (RPI) B. Reinisch (U. Mass Lowell)	Sound plasma density gradients	Transmit and receive radio waves with frequencies between 3 kHz and 3 MHz

Table 3. (Top) Measured/predicted sunspot numbers during IMAGE prime and extended missions. (Middle) Precession of IMAGE apogee latitude. (Bottom) Selected IMAGE science investigations showing a progression through discovery, explanation, and understanding. For results already obtained, reference numbers to published papers are given. For future studies, reference is made to one of 5 sections in Section III in which the relevant science objectives are discussed.



Investigation	Discovery or Prediction Confirmation	Explanation (Hypothesis Testing)	Understanding or Application	
Plasmaspheric plumes	1, 2	3, 4, 5, 6, 7, 8	9, 10, 11, 12 Plasma Injection, Transport & Loss	F2,F3
Plasmaspheric shoulder	1, 13	9, 14, 15	6 Electrodynamic Coupling	F2,F3,H2
Plasmasphere voids or notches	13	16, 17, 18	Electrodynamic Coupling	F4,H2
Corotation lag	17	18	Electrodynamic Coupling	F2,F4,H2
Reconnection spot	19, 20	21, 22, 23	Reconnection	F1,F2,H2
Detached proton arcs	24	25	Hot-Cold Plasma Interactions	F2,H2
Plasmaspheric fingers	17, 26	27	Electrodynamic Coupling	H2
AM ring current injection	28	29, 33	Plasma Injection, Transport and Loss	F2,F3,H2
Kilometric continuum	30	31	Electrodynamic Coupling	F2,H2
Impulsive O+ injection	32	33	Plasma Injection, Transport and Loss	F2,H2
SAPS effect on plasmasphere	3, 4	7, 34	Electrodynamic Coupling	F2,F3,H2
Plasmasphere refilling	35, 36	37, 38, 39, 40	Plasma Injection, Transport and Loss	F2,F3
Plume precip. of ring current	2	10, 11, 41	Hot-Cold Plasma Interactions	F2,F3,H2
Secondary ISN stream	42	43	Heliospheric Remote Sensing (HRS)	F3
Subauroral proton flashes	44	45, 46	47 Hot-Cold Plasma Interactions	F2,F3,H2
SW control of ion outflow	44	23	Plasma Injection, Transport and Loss	F2,F3,F4
Plasmapause undulation	48	34, 49	Electrodynamic Coupling	F2,F3,H2
Corotating proton spots	50, 51		Electrodynamic Coupling	F2,F3,H2
P-sphere regulation of RB	52	53	Electrodynamic Coupling	F2,H2,J1

Discovery or Prediction Confirmation	Reference Nos.
Explanation (Hypothesis Testing)	Reference Nos. or Theme
Understanding or Application	Reference Nos. or Theme

1. *Burch et al.* [2001a]
2. *Burch et al.* [2001b]
3. *Foster et al.* [2002]
4. *Goldstein et al.* [2003a]
5. *Goldstein et al.* [2004b]
6. *Goldstein and Sandel* [2005]
7. *Goldstein et al.* [2005b]
8. *Foster et al.* [2005]
9. *Spasojevic et al.* [2005a]
10. *Spasojevic et al.* [2004]
11. *Spasojevic et al.* [2005b]
12. *Goldstein et al.* [2005a]
13. *Sandel et al.* [2001]
14. *Goldstein et al.* [2002]
15. *Goldstein et al.* [2003b]
16. *Gallagher and Adrian* [2005]
17. *Sandel et al.* [2003]
18. *Burch et al.* [2004]
19. *Fuselier et al.* [2002]
20. *Frey et al.* [2003b]
21. *Frey et al.* [2003a]
22. *Phan et al.* [2003]
23. *Fuselier et al.* [2003]
24. *Immel et al.* [2002]
25. *Burch et al.* [2002]
26. *Gallagher et al.* [2002]
27. *Adrian et al.* [2004]
28. *Brandt et al.* [2002]
29. *Fok et al.* [2003]
30. *Green et al.* [2002]
31. *Green et al.* [2004b]
32. *Mitchell et al.* [2003]
33. *Brandt et al.* [2004]
34. *Goldstein et al.* [2005c]
35. *Reinisch et al.* [2004]
36. *Galvan et al.* [2005]
37. *Tu et al.* [2003]
38. *Clilverd et al.* [2003]
39. *Dent et al.* [2003]
40. *Dent et al.* [2005]
41. *Fraser et al.* [2005]
42. *Moore et al.* [2003]
43. *Collier et al.* [2004]
44. *Fuselier et al.* [2001]
45. *Hubert et al.* [2003]
46. *Hubert et al.* [2005]
47. *Fuselier et al.* [2004]
48. *Goldstein et al.* [2004a]
49. *Fok et al.* [2005]
50. *Frey et al.* [2004a]
51. *Frey et al.* [2004b]
52. *Baker et al.* [2004]
53. *Goldstein et al.* [2005d]

operation of IMAGE during 2007-2010 will help to ensure that other elements of the S^3C Great Observatory have the measurements necessary to achieve S^3C science closure.

For the period 2007-2010, we propose a set of science investigations that are directly relevant to a number of goals of the S^3C Roadmap. Coordination with other Great Observatory missions as well as with certain non-S^3C assets has been included in the design of several of the proposed IMAGE science investigations. These investigations and their relevance to the S^3C goals are described in **Section II.A**. As can be seen from **Table 3**, the emphasis during this phase of the IMAGE mission will be increasingly on expanding and deepening our understanding of the structure and dynamics of the inner magnetosphere as charted by earlier IMAGE observations and, in some cases, on the application of this understanding to goals of the the national space weather effort such as the development of predictive models of the radiation belts (**Section II.A.6**).

During the course of the extended mission, the latitude of apogee will shift from middle and low southern hemisphere latitudes to northern hemisphere polar latitudes (**Figure 2**). Where appropriate, the implications of the changing viewing geometry for the proposed science investigations are discussed in **Section II.A.**

The IMAGE instruments and spacecraft (**Section V**) continue to perform well and are fully capable of carrying out the proposed science investigations.

II. Science Objectives

A. IMAGE Science: 2007-2010

The science objectives of the IMAGE 2007-2010 extended mission are central to the development of a comprehensive understanding of the dynamics of geospace during all phases of the solar activity cycle. ***The five scientific themes of the extended mission are: (1) Reconnection, (2) Electrodynamic Coupling, (3) Plasma Injection, Transport and Loss, (4) Hot-Cold Plasma Interactions, and (5) Remote Sensing of the Heliosphere.*** These five themes (each composed of one or more specific, focused investigations) are essential to S^3C Roadmap science objectives (see **Tables 4, 5, and 6**). Each of the investigations in **Sections A.1** through **A.5** is related explicitly to the Scientific Objectives and Research Focus Areas of the S^3C 2005 Roadmap. The combination of the orbital geometry and the timing of the IMAGE extended mission during solar minimum and the ascending phase of solar cycle 24 will provide changing perspectives of conditions not yet encountered in the IMAGE mission. The extended mission will empower more rapid science returns in contemporary S^3C missions (such as TWINS and IBEX; see investigations **A.3.c** and **A.5.a**), will advance our understanding in anticipation of future S^3C missions (such as RBSP; see investigation **A.4.a**), and will continue to help refine models of the inner magnetosphere (see **Section A.6**). Global observations are indispensable to achieving closure in S^3C science objectives (see **Tables 4, 5, and 6**), and the IMAGE extended mission will be a vital part of that achievement.

A.1 Reconnection

It is now generally accepted that the dominant injection mechanism at the magnetopause is magnetic reconnection. Moreover, because it is a fundamental plasma process, understanding how reconnection is initiated and sustained is critically important to space physics research. In the S^3C roadmap, this importance is reflected in ***research focus area F1*** "Understanding magnetic reconnection". ***With its imaging capabilities, the IMAGE mission provides the ability to obtain crucial systems-level information about the reconnection process.***

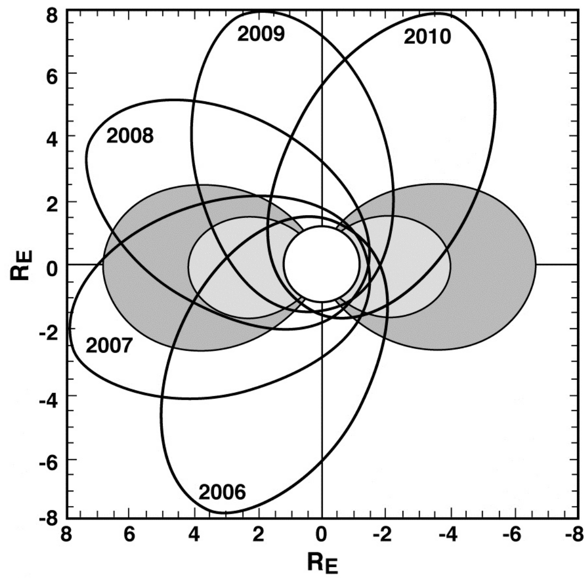


Figure 2. Orbits for March 25 of each year during the IMAGE extended mission. Orbits are plotted in the orbit plane, in which right ascension = 12° (left half plane) and 192° (right half plane). The local-time precession is not shown since the 90°-inclination orbit is fixed in inertial space.

A.1.a. Quasi-steady versus Bursty Reconnection. The IMAGE FUV SI-12 proton imager has proven to be an ideal tool for investigating the ionospheric signature of dayside reconnection. One of the unique results from the IMAGE mission has been the observation of proton precipitation at the ionospheric footpoint of the cusp. The continuous nature of this precipitation is interpreted as evidence of quasi-steady dayside magnetopause reconnection, lasting for many hours [*Frey et al.*, 2003a]. Quasi-steady reconnection is in stark contrast to the very dynamic, bursty reconnection associated with solar flares and magnetospheric substorms.

With the successful verification of quasi-steady reconnection at the magnetopause, the next obvious objective of reconnection research using IMAGE is the search for signatures of bursty magnetopause reconnection. Flux Transfer Events (FTEs) are a well-known manifestation of bursty reconnection at the magnetopause. These reconnection transients have been observed in situ, and there have been several reports of their ionospheric signatures. During the extended mission, IMAGE and in situ data will be used to answer the following questions: 1) What are the proton auroral signatures of bursty magnetopause reconnection? 2) What solar wind conditions determine the occurrence frequency, location, and properties of magnetopause

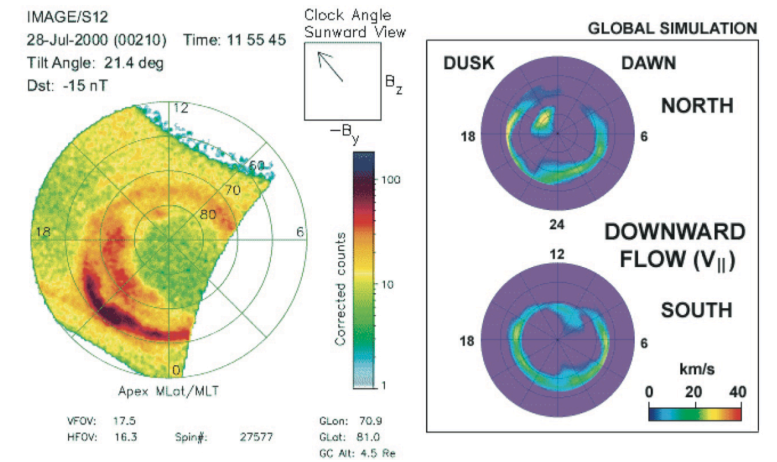


Figure 3. Comparison of FUV SI-12 northern hemisphere observations and MHD simulations. The left panel shows SI-12 color-coded contours of proton precipitation intensity. The "spot" at ~82° MLAT and 13.5 MLT is caused by high latitude magnetopause reconnection. The location of this spot in the northern hemisphere is reproduced in the MHD simulation (upper right hand panel). For the southern hemisphere (lower right hand panel), the spot is predicted to be on the opposite side of noon. IMAGE southern hemisphere observations will test this prediction [*Berchem et al.*, 2003].

reconnection? and 3) Is the steadiness of the reconnection process determined by the type or location of the reconnection sites (i.e., anti-parallel or component reconnection)?

To answer these questions, in situ observations from Polar, Cluster, and (later) THEMIS will be used to determine the existence of FTEs at the magnetopause boundary. Once established in situ, the IMAGE FUV SI-12 images will be compared to models that predict proton precipitation signatures of magnetic reconnection. As described below, these models, used for quasi-steady reconnection, provide specific predictions for anti-parallel and component reconnection sites. Any changes in the precipitating proton intensity in regions that map to reconnection sites or motion of these precipitation regions will indicate changes in the reconnection rate and/or location.

A.1.b Antiparallel vs. Component Reconnection. IMAGE FUV/SI-12 has been used to investigate anti-parallel versus component reconnection [*Fuselier et al.*, 2002; *Phan et al.*, 2003; *Frey et al.*, 2003b]. The location and relative intensity of proton auroral precipitation are accurately predicted from the antiparallel and component reconnection models using either relatively simple magnetic field models [*Petrinec and Fuselier*, 2003] or MHD simulations (**Figure 3**). For northward IMF, the magnetic local time (MLT) of the proton auroral "spot" follows changes in the IMF B_y component, tracking the movement of the reconnection site along the magnetopause. The antiparallel reconnection model predicts that the northern hemisphere cusp spot is located prenoon (postnoon) for negative (postive) B_y.

A statistical study by *Bobra et al.* [2004] using SI-12 data yielded the surprising result that, for positive B_y, the proton spot in the northern hemisphere is often in the prenoon sector while theoretical predictions place it post noon. However, the spot always occurs in the expected prenoon location for negative B_y. Preliminary indications from southern hemisphere observations suggest a similar trend. As IMAGE completes its southern hemisphere observations (through FY07), sufficient statistics will be accumulated to complete the comparison of the northern and southern hemisphere cusp locations for northward IMF. If this asymmetry persists, then it raises several questions that can be answered with the improved statistics. They include: 1) Are there B_x values that affect draping at the magnetopause and/or low latitude (equatorward of the cusp) reconnection effects that may explain this asymmetry? and 2) Is there a large scale dawn-dusk offset in the Earth's magnetospheric cusps (similar to the offset from a pure radial direction in the Earth's magnetotail) that helps explain these puzzling observations?

For southward IMF, antiparallel and component reconnection models differ significantly in the subsolar region. In the first model, reconnection occurs along line(s) (i.e., neutral lines) where the magnetosheath and magnetospheric magnetic fields are antiparallel. These neutral lines are often separated at the noon-midnight meridian. In the second model, reconnection occurs along a line (tilted neutral line) that is hinged at the subsolar point and is tilted depending on the sign of the IMF B_y component. IMAGE observations of proton precipitation firmly establish the existence of both types of reconnection [*Fuselier et al.*, 2002; *Petrinec and Fuselier*, 2003; *Fuselier et al.*, 2005a; *Trattner et al.*, 2005]. The key remaining questions are: 1) Does one or the other type of reconnection dominate at the magnetopause? 2) Are there external factors that cause one or the other type of reconnection to be favored at the magnetopause? and 3) Can the type of reconnection switch dynamically (e.g., during an IMF rotation)?

These questions are best answered by IMAGE observations in collaboration with in situ missions including Polar, Cluster, and (later) THEMIS. The correlations are necessary to verify the location(s) of reconnection on the magnetopause that are predicted from the IMAGE observations. Serendipitous correlations are difficult to obtain, requiring long time periods to accumulate statistics covering a wide range of external conditions. The number of correlations will increase significantly when the multi-spacecraft THEMIS mission is launched. One focus of these improved statistics will be to test hypothetical conditions for a dynamic switch from anti-parallel to component reconnection (such as a change from a dominant $-B_z$ to a dominant B_y orientation, or possibly a pressure increase that does not have an associated change in the IMF orientation.)

A.1.c Regulation of Dayside Reconnection by Plasmaspheric Plumes. Dayside magnetopause reconnection drives convection in the inner magnetosphere, eroding the plasmasphere and producing plumes of cold, dense plasma in the outer magnetosphere; The IMAGE EUV imager provides global views of cold plasma including the plume extension, which demonstrate that plume formation is a consistent response to enhanced convection [*Goldstein and Sandel*, 2005]. Although the sensitivity of EUV is typically not good enough to see much beyond geosynchonous orbit, models [e.g., *Grebowsky*, 1970] and numerous in situ observations [e.g., *Chandler and Moore*, 2003] predict that plumes do extend to the magnetopause, where they can encounter the dayside reconnection region. The presence of relatively high density (several particles per cm^3) plasma at the magnetopause can significantly reduce the Alfvén speed, which may decrease the rate of reconnection.

Science questions to be addressed include: (1) With what frequency does plume plasma encounter the reconnection region (rather than simply being lost across the magnetopause)? and (2) To what extent can the presence of plume plasma regulate the rate of reconnection? In this investigation, the global morphology of plumes at the magnetopause will be determined using models, constrained by EUV images (an approach that has been demonstrated to provide 0.2 to 0.7 R_E accuracy in the inner magnetosphere [*Goldstein et al.*, 2005a]). Plume densities can be obtained using in situ observations by IMAGE RPI, Cluster, and Polar (from spacecraft potential). ***During the early parts of FY07, the IMAGE spacecraft will be at low latitudes near the magnetopause, increasing the likelihood of in situ RPI measurements of plumes near the reconnection region.*** The rate of reconnection will be provided by the IMAGE FUV SI-12 proton imager, used in conjunction with the Tsyganenko geomagnetic field model (to map the FUV emissions to the magnetic equator)**.** The EUV and FUV images will be combined with in situ observations at the magnetopause from Polar, Cluster, and (later) THEMIS.

A.2 Electrodynamic Coupling

The inner magnetosphere, ionosphere, and upper atmosphere are electrodynamically coupled by ion drag and electrical conductance effects at low altitudes and by plasma pressure gradients and the resulting field-aligned currents generated at high altitudes. Understanding this coupling is of compelling importance (see S^3C research focus areas **H2.1** and **H2.3**)**.** ***IMAGE provides the multi-plasma contextual information so critical to properly interpret single-point measurements of complex inter-plasma coupling physics***. Significant strides have already been made with correlative analysis of data from IMAGE and from low-altitude satellites such as DMSP, Iridium and TIMED. The 2007-2010 extended mission offers new opportunities to advance our understanding, especially in conjunction with missions such as TWINS (see **A.2.b** and **A.2.d**). During solar minimum and the ascending phase of the solar activity cycle, the magnetosphere will experience longer periods of recovery and deep quiet and more isolated storm conditions very favorable for our proposed investigations, especially electrodynamic coupling to neutral winds (an almost totally unexplored topic), inner magnetospheric shielding, and negative ionospheric storms (dramatic recovery-phase ionospheric density redistributions). The extended mission promises to deliver detailed understanding of the decades-old (and still only qualitatively characterized) concepts of shielding and control of the magnetosphere by ionospheric conductivity. Crucial for these studies is the continued development of comprehensive models of inner magnetospheric electric fields and currents into which the satellite observations can eventually be assimilated.

A.2.a. Neutral Wind Influences on the Plasmasphere. The outer plasmasphere can exhibit a bewildering degree of spatial structure that has so far defied explanation [*Lemaire and Gringauz*, 1998]. EUV has discovered meso-scale plasmapause structures such as *dayside shoulders*, *notches* (or "*voids*"), and *crenulations* [*Spasojevic et al.*, 2003a; *Gallagher and Adrian*, 2005], and it seems likely that these globally-observed features are responsible for much of the structure observed in situ. *Goldstein and Sandel* [2005] noted that the growth of dayside meso-scale plasmapause structures is favored in the absence of convection, when weaker effects such as neutral winds or plasma instabilities might become dominant. Particle collisions couple the motion of the thermosphere and ionosphere, and such motion generates ionospheric electric fields that, when magnetically coupled to the inner magnetosphere, create measurable effects on the plasmas there. For example, *Burch et al.* [2004] used EUV and DMSP data to show that thermospheric winds (driven by auroral heating) could cause a measurable corotation lag in both the ionosphere and plasmasphere. There is good reason to suspect that the growth of dayside shoulders and notches may also be related to neutral winds, specifically a vortical flow in the dayside magnetosphere, driven by the solar-quiet-day (Sq) thermospheric flow pattern [*Carpenter et al.*, 1972; *Spasojevic et al.*, 2003a; *Gallagher and Adrian*, 2005]. ***The period 2007-2010 is well-suited to undertake investigation of this effect, which can be eclipsed during storms. With apogee at low and middle latitudes, the changing position of the spacecraft along the orbit will provide an oblique viewing geometry from which meridional structure of the plasmasphere can be determined.***

Science questions to be addressed include: (1) Which plasmapause features are driven by neutral winds? (2) What is the quantitative global effect of neutral winds on the plasmasphere? (3) Can plasmaspheric dynamics feed back into neutral winds? Questions (1) and (3) will be addressed by intercomparison of IMAGE EUV and DMSP observations, following *Burch et al.* [2004]. Question (2) can be answered by constructing and testing parametric E-field models based on the known morphology of neutral winds (e.g., Sq pattern) constrained by DMSP and EUV observations (including EUV-infered E-fields) following the methodology of *Goldstein et al.*, [2003a; 2005b]. ***This investigation is directly relevant to M-I-T coupling (F3.3, F4.4, H2.3), involves cold plasma transport (F2.4) and electrodynamic coupling (H2.1), and can affect evolution of energetic particles (F2.1, H2.2).***

A.2.b. Inner Magnetospheric Shielding. Shielding of the convection electric field is one of the most important processes in the inner magnetosphere, and ***its study directly addresses electrodynamic coupling of the ionosphere and magnetosphere (H2.1). Shielding also determines whether and how plasmaspheric plasma will be convected (F2.4).*** The presence of plasmaspheric plumes (suppressed during effective shielding) is important to understanding disruptions in GPS capabilities (owing to anomalous ionospheric densities associated with plumes) and modulation of the radiation belts (by EMIC-wave scattering inside plumes; see **Section A.4**). During enhanced convection, region-2 field aligned currents (FACs) at the inner edge of the ion plasma sheet can close through the ionosphere and generate electric fields that act to shield the innermost magnetosphere, including the plasmasphere, from the full convection E-field [*Jaggi and Wolf*, 1973]. However, most EUV observations seem to reflect an imbalance between convection and shielding [*Goldstein and Sandel*, 2005], favoring either convection (and plasmaspheric erosion), or overly strong shielding (leading to pre-dawn shoulders). *Spasojevic et al.* [2005a] identified the first case of effective shielding (i.e., apparent balance between shielding and convection), in which IMAGE EUV observed no plasmaspheric erosion during moderate but slowly increasing convection. Effective shielding was eventually disrupted by a substorm, causing a plume to form. Critical questions about shielding remain to be answered. (1) Is the effectiveness of shielding regulated more strongly by the steadiness of convection, or the pressure of the partial ring current? (2) How often does effective (balanced) shielding occur? (3) Do substorms always disrupt shielding? (4) What are the spatial and temporal details of the region-2 current system? ***Because 2007-2010 will witness solar minimum and the ascending phase, we expect more intervals of steady solar wind conditions, optimal for effective shielding.*** Intervals of non-steady solar wind conditions will contribute as well, affording opportunities to witness overshielding following northward IMF turnings, which causes the formation of 0.5-1 R_E shoulder-like bulges on the plasmapause. These shoulders can be analyzed to yield the electric field strength [*Goldstein et al.*, 2002; 2003b]. The observational portion of this study will rely on data from IMAGE (EUV, RPI), and LANL (and Polar and Cluster where possible), for the plasmaspheric densities and flows. IMAGE HENA and MENA afford an excellent global picture of the electrodynamic coupling between the ring current and ionosphere by providing equatorial proton pressure distributions and 3D FACs (**Figure 4**). The precession of IMAGE apogee through middle and low latitudes will provide a vantage point to study field-aligned structure of the ring current and plasmasphere, which is poorly known but crucial to the electrodynamic coupling between ionosphere and magnetosphere. Stereo ring current imaging, provided by the combination of IMAGE (lower latitudes) and TWINS (higher latitudes) will better constrain the IMAGE ENA inversions, providing more accurate distributions. To study FACs and the ring current, we will use IMAGE HENA and MENA, TWINS, Iridium (**Figure 4b**) and DMSP data and select likely intervals using ACE data. Modeling in support of this investigation will utilize the Rice Convection Model (RCM) and Magnetospheric Specification Model (MSM).

A.2.c. Electrodynamics of the Mid- and Low-Latitude Ionosphere and Thermosphere. Reductions in the density of thermospheric atomic oxygen at high and middle latitudes frequently occur during the recovery phase of a magnetic storm [*Craven et al.*, 1994], resulting in depletions in ionospheric electron density from increased recombination with N_2 ("negative-phase ionospheric storms"). IMAGE FUV/SI-13 can monitor these large-scale composition changes by observing changes in thermospheric OI 135.6-nm

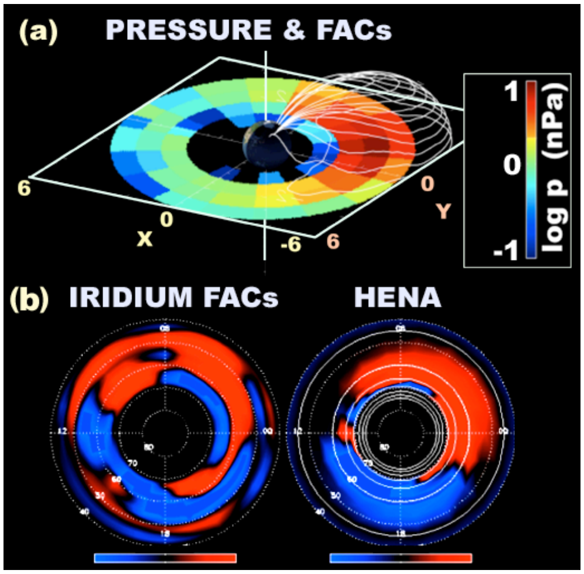


Figure 4. Electrodynamic Coupling of Ring Current and Ionosphere. (a) IMAGE HENA proton pressure and field-aligned current (FAC) distribution from an inversion of ring current ENAs. The vantage point is at northern mid-latitude in the pre-midnight sector. Colors show pressure according to the color bar; note the "skewed" pressure peak (red) in the post-midnight sector, first reported by *Brandt et al.*, [2002]. The white wire-frame lines depict the 3D FAC system obtained from the inversion. (b) FACs mapped to the polar ionosphere; red is upward and blue is downward. (Right) 2-minute integrated HENA FACs, which compare very well with (Left) 1-hour-integrated FACs inferred from Iridium magnetometer data.

emissions in the dayglow and has provided direct optical evidence that the O/N_2 depletion corotates with the Earth. [*Zhang et al.*, 2003]. Characterization of negative-phase ionospheric storms is one of the objectives of the LWS Geospace Program. Until the eventual deployment of a dedicated imager (after 2010), IMAGE will be the only spacecraft capable of providing the global ionosphere-thermosphere imaging required to track the development and evolution of negative-phase storms.

Future low- to mid-latitude ionospheric studies will greatly benefit from a combination of IMAGE SI-13 and TIMED-GUVI observations. SI-13 provides the global view of ionospheric inhomogeneities and their long-term dynamics. GUVI provides higher spatial resolution with the snapshots along the TIMED ground track. Quantitative comparison of data from both instruments showed excellent agreement [*Zhang et al.*, 2004]. These collaborative studies, together with plasma drift measurements by DMSP and atmospheric density determinations by CHAMP and GRACE, will be extended into the solar minimum phase to investigate the longitudinal dependence of the equatorial ionospheric anomaly, effects of atmospheric tides and gravity waves on the ionosphere, and the effects of auroral forcing on the ionospheric composition and O/N_2 ratio. Precession of the IMAGE apogee through low latitudes from 2006 to 2008 will provide the best viewing geometry for the equatorial airglow bands (**Figure 5**). The dynamics of these bands are also expected to change compared to solar maximum and will be a topic during the extended IMAGE mission. ***These results are related to S^3C research focus areas F3.3 and F4.4 and will greatly benefit future projects like the Living with a Star (LWS) IT investigations and COSMIC; will improve empirical density models; and are relevant for the determination of GPS accuracy, satellite drag, and collision avoidance; benefiting missions and programs involved in protecting space assets.***

A.2.d. Ionospheric Conductance Effects on Inner Magnetospheric E-fields. The spatial and temporal development of magnetospheric E-fields depends critically upon ionospheric conductivity, yet this important quantity is not well known. The dynamic structure of inner magnetospheric equatorial E-fields below spatial scales of 1 R_E is also unknown. It is possible to infer ionospheric conductivity from FUV global auroral images [*Frey et al.*, 2003c] and in principle from global inversions of total electron content (TEC) [*Yizengaw et al.*, 2005]. With the resultant global ionospheric conductivity, and the strength of FACs inferred from DMSP, HENA, TWINS, and Iridium data [*Brandt et al.*, 2004] (**Figure 4**), we can obtain a global map of the ionospheric E-field. Electric fields can also be inferred from EUV images when the plasmapause is in motion [*Goldstein et al.*, 2005b]. The effects of these electric fields upon the plasmasphere and ring current can be directly observed by EUV, HENA, and TWINS.

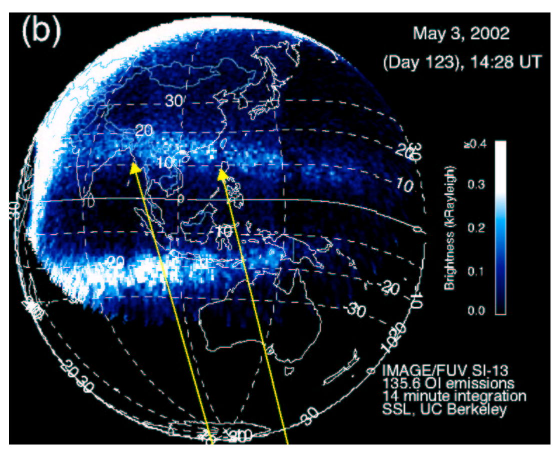


Figure 5. Example of equatorial airglow bands as seen by the FUV 135.6 nm imager SI-13. The arrows point to two depletions in the airglow intensity that were used to track the relative motion of plasma depletions and subsequently determine electric fields responsible for the plasma drift [from *Immel et al.*, 2004].

Science questions to be addressed include: (1) What are the global dynamic characteristics of (a) ionospheric conductivity, (b) ring current pressure and FACs, and (c) ionospheric and magnetospheric E-fields? (2) What behaviors of the ring current and plasmasphere do these E-fields produce or influence? (3) What features of the global E-field are associated with storms, and which are associated with mild geomagnetic disturbances? A key objective of this study is the development of a global model of inner magnetospheric E-fields resulting from M-I coupling. ***This investigation directly addresses S^3C research focus areas H2.1, H2.2, and F3.3, and indirectly F2.2 and F2.4. During 2007-2010 the low-latitude apogee and ascending solar cycle phase will afford good opportunities to examine (a) latitudinal dependences (and hemispheric asymmetries) of conductivity, FACs and ring current pressure, and (b) long periods of mild geomagnetic disturbances. The overlap with the TWINS mission promises unprecedented quality in ENA pressure and FAC inversions.***

A.3 Plasma Injection, Transport, and Loss

One of the key science questions of both the IMAGE mission and the S^3C Roadmap (**research focus area F2**) is: How and where are plasmas energized, transported, and subsequently lost? ***The systems-level (i.e., global) information provided by IMAGE is essential to determine where and when plasmas are injected, and where these injected plasmas are transported and lost.*** IMAGE has performed comprehensive imaging of the various inner magnetospheric plasma populations around solar maximum and during the declining phase of the present solar cycle. Observations during 2007-2010 will allow imaging of the inner magnetosphere at solar minimum and during the ascending phase of the next cycle, thus enabling comprehensive modeling of the changing structure and dynamics of the inner magnetosphere at all levels of solar activity. The generally quieter conditions will favor study of ionospheric outflow (***A.3.a*** and ***A.3.b***). The extended mission orbital geometry will provide opportunities to observe field-aligned dependences of both cold plasma (***A.3.a*** and ***A.3.b***) and hot plasma populations (***A.3.c***), and will permit stereo imaging in conjunction with TWINS.

A.3.a. Quantitative Understanding of Plasmaspheric Refilling. The source of plasmaspheric plasma is outflow from the ionosphere, which refills flux tubes following erosion events (i.e., recovery phase). ***Refilling is fundamental to M-I-T coupling (F3.3), plasma transport (F2.4), and mass loading (F3.5). Radiation belt acceleration (F2.1, H2.2, H2.3) occurs during recovery times, and is strongly influenced by cold plasma.*** This investigation is thus linked to safeguarding human and robotic explorers, and space-based assets (**J1**) in geospace. After decades of prior research [e.g., *Su et al*., 2001; *Zeng et al*., 2001], the spatial and temporal properties of refilling are still only crudely known, in part because traditional measurement techniques have had to rely on the strict corotation assumption, which IMAGE has shown to be incorrect [*Sandel et al., 2003*; *Burch et al*., 2004]. Global imaging has just begun to show its power at distinguishing the spatial and temporal components of refilling. We have learned of longitudinal hot spots [*Sandel et al*., 2001], field-aligned hemispheric asymmetry [*Reinisch et al*., 2004], and have confirmed a 20-year-old theoretical prediction [*Richards and Torr*, 1985] of a noon-sector diurnal refilling minimum [*Galvan et al*., 2005]; but more investigation is needed.

Science questions include: (1) What process creates longitudinally confined refilling regions? (2) Are there seasonal and local-time dependences of north-south asymmetries? (3) What is the cause of early- and late-time differences in refilling rates? (4) What (if any) role does refilling play during erosion? (5) What processes must be included in a reliable model of the diurnal variation of refilling? ***The period 2007-2010 (solar minimum and ascending phase), with longer intervals of deep quiet (during which refilling is the dominant mechanism), is an excellent time to achieve these objectives, especially in combination with a lower-latitude perigee (affording better views of field-aligned structure for EUV).*** EUV and RPI observations of the plasmasphere will be augmented (where possible) with in situ Cluster, LANL, and ground-based observations (magnetometer and TEC) to attack these questions. The observations will be compared with models such as the DGCPM [*Ober et al*., 1997], which includes the influences of convection on changing flux tube volumes, daytime refilling, and nighttime draining of plasma.

A.3.b. Transport and Loss of the Ring Current Using IMAGE and TWINS. From IMAGE we have learned a great deal about the way the ring current interacts with the plasmasphere [*Burch et al*., 2001b; *Goldstein et al*., 2005c; *Spasojevic et al*., 2004]. However, single-vantage images do not provide enough information to determine pitch-angle distributions, which are critical to understanding the way the ring current plasma is transported and lost. One of the science goals of the TWINS mission is to study the changing state of the global ring current pitch-angle distribution during storms and substorms using two simultaneously orbiting ENA imagers. Science questions that can be addressed by the combination of IMAGE and TWINS include: (1) How do pitch-angle distributions evolve during storms and substorms? (2) What is the quantitative contribution of various energization and loss processes to the global dynamical pitch-angle and

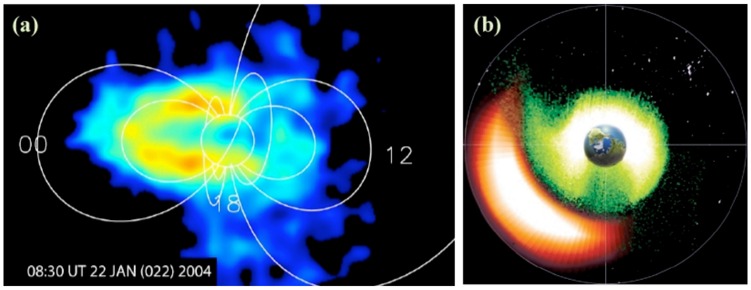


Figure 6. Transport and Loss of the Ring Current Using IMAGE and TWINS. (a) Equatorial image of ring current from HENA, providing second vantage point for stereo imaging before TWINS-2 launch. (b) Global composite image (mapped to magnetic equatorial plane) of plasmasphere (green, EUV) and ring current (red, HENA), showing overlap of warm and cold plasmas where EMIC wave instability can significantly alter the ring current pitch-angle distribution [adapted from cover of *Pulkkinen et al.*, 2005].

pressure distribution? (3) How are ring current pressure and pitch-angle distributions quantitatively affected by (a) isolated substorms? (b) steady convection? (c) sawtooth oscillations? (d) CME-driven storms? (e) high-speed stream-driven storms? (f) extended quiet conditions? During 2007-2010 we will work to develop a global model of ring current pressure and pitch angle that is valid at all levels of solar and geomagnetic activity. ***From IMAGE's mid-latitude vantage point during 2007-2010, HENA and MENA images will dissect the ring current along a meridian (Figure 6a), while TWINS-1 will view from a high-latitude Molniya orbit. With these two perspectives, we can image the global ion pressure and pitch-angle distributions.*** One of the added benefits (to TWINS science) of the IMAGE-TWINS observatory is the continued monitoring of the plasmasphere via EUV images. Overlap of the ring current and plasmasphere (see **Figure 6b**) favors growth of the EMIC wave instability (see **Section A.4**), which scatters ring current ions. In order to measure the pitch-angle distributions and to help understand them, we require knowledge of the plasmasphere distribution. EUV images will also provide a measure of the global electric field (via its effect on the cold plasma distributions) that results from the electrodynamic coupling between ring current and ionosphere. ***This investigation fits in well with S³C science objectives: study ring current transport and evolution (F2.2, H2.1), electrodynamic coupling, and generation of electric and magnetic fields (H2.1, H2.2).*** Because EMIC waves also scatter radiation belt electrons, the TWINS-IMAGE observatory is directly useful for radiation belt science (**S³C research focus areas F2.1**) and relevant to human and robotic exploration (**J1.1, J1.2**).

A.3.c. Substorms. Substorms are related to some of the most dramatic plasma transport processes in the magnetotail: bursty bulk flows (BBF), the injection of plasma into the upper atmosphere, intense aurora, ion outflow, and energetic neutral atom emissions. IMAGE investigations have already provided a great deal of information about substorm expansion in electron and proton aurora [*Mende et al.*, 2002], the fluxes of precipitating and drifting ions [*Mende et al.*, 2003], the extraction of oxygen from the ionosphere [*Pollock et al.*, 2003], and the coupled response of ring current, auroral ionosphere, and plasmasphere to isolated substorms (**see Figure 7**). In the extended mission, even greater emphasis will be placed on combining IMAGE data with measurements made by other S³C missions (such as Cluster and Geotail) and geosynchronous and low-altitude satellites. After 2006 we have an extraordinary opportunity to combine 3D inner magnetospheric imaging (IMAGE + TWINS; see investigation ***A.3.b***) with a multi-point observatory (THEMIS) dedicated to the study of substorm triggering. THEMIS satellites will

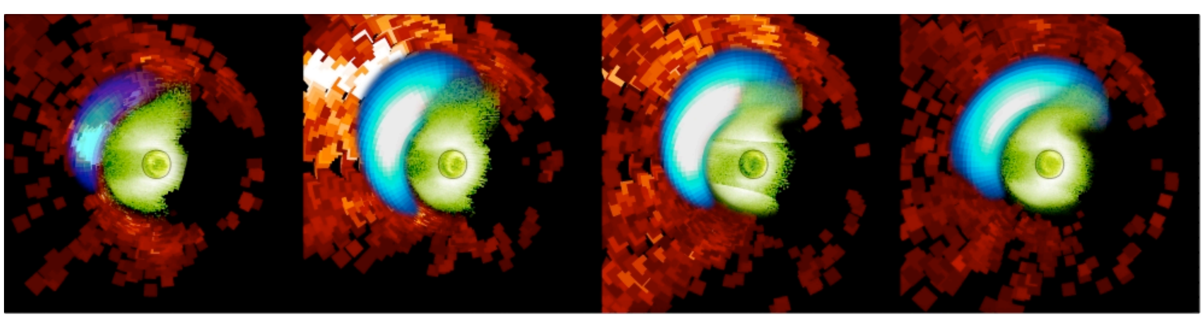


Figure 7. Coupled Global Response of the Inner Magnetosphere to a Substorm. Composite image on April 17, 2002 in the magnetic equatorial plane, with the Sun to the right. Orange pixels are IMAGE-FUV auroral measurements mapped to the equator. Blue pixels are ring current pressure from IMAGE-HENA. Green pixels are He^{+} densities from IMAGE-EUV. The substorm onset is accompanied by a ring current injection that inflates the magnetic field (pulling plasmaspheric plasma outward) and then ring-current-ionosphere coupling generates a westward flow channel that strips away the duskside outer plasmasphere [from *Burch*, 2005 and *Goldstein et al.*, 2005c]

obtain critical single-point measurements in the substorm triggering region (8-10 R_E in the magnetotail). THEMIS all-sky cameras (affording high spatial resolution images of the aurora above selected ground locations) and IMAGE FUV (providing overall systems-level images of the aurora) will provide contextual auroral information vital to interpretation of the in situ data. Global images of the plasmasphere (IMAGE EUV) and the ring current (IMAGE and TWINS), in combination with other S^3C missions, will measure the coupled inner magnetospheric response to the substorm. This combination of observations will provide an unrivaled comprehensive view of how substorms bring energy to the inner magnetosphere and ionosphere. Science questions ***(related most directly to to S^3C research areas F2 and H2):*** (1) How is plasma accelerated and subsequently lost during the substorm process? (2) How does the transport and loss influence the ring current and the plasmasphere? (3) What is the global dynamic morphology of the field-aligned current systems that couple the magnetosphere and ionosphere? (4) What are the timing and global attributes of the induction electric field associated with substorm dipolarization? (5) How do westward (and eastward) traveling auroral features relate to the field-aligned currents and global distributions of inner magnetospheric plasmas?

A.3.d. Interchange-Driven Motion in the Magnetospheres of Earth and Saturn. Both traditional measurements and numerous global EUV images of the Earth's plasmasphere show a high degree of spatially-structured density profiles, most often found after periods of extended quiet conditions [*Lemaire and Gringauz*, 1998]. It has been suggested that much of the observed fine-scale structure could be caused by centrifugally-driven plasma interchange, in which dense, cold plasma moves outward and more tenuous, warmer plasma moves inward to replace it [*Lemaire and Gringauz*, 1998; *Pierrard and Lemaire*, 2004; *Goldstein and Sandel*, 2005]. This interchange process is thought to be suppressed during strong convection [*Huang et al.*, 1990], but during intervals of very weak convection, whenever corotation dominates over convection for several hours or more, weaker (slower) influences like interchange have a chance to significantly affect cold plasma dynamics.

The internally driven, mass-loaded magnetosphere of Saturn is thought to be dominated by corotation, as is the terrestrial plasmasphere. The Cassini mission has recently begun to explore the inner magnetosphere of Saturn, and has observed injections of warm plasma moving radially inward into regions of otherwise cold plasma. *Burch et al*. [2005] showed evidence suggesting that the injections are fingers of plasma undergoing interchange-driven motion. Considering the apparent similarity between Saturn's magnetosphere and the quiet-time terrestrial plasmasphere, we propose a comparative investigation of interchange instability in both the Earth and Saturn systems. Near Earth, we will use IMAGE, Cluster, and TWINS for observations of the plasmasphere and ring current. Near Saturn, we will use Cassini data, consisting of local plasma measurements and global ENA images, to study the cold and warm plasmas. Theoretical investigation in support of the observations will be provided by the model of *Andre et al.* [2005]. Science questions to be addressed include: (1) What are the global and local spatial properties of the current systems associated with the injections? (2) What is the radial extent of injections? (3) What are the local plasma and magnetic pressures inside the injections? (4) Are the injection properties consistent with an interchange explanation? (5) Are there also outward-moving regions of cold plasma? ***These questions are directly relevant to S^3C research focus areas F2.1, F2.2, F2.4, H2.1, and H2.2. The IMAGE component of this study will be undertaken during solar minimum and ascending phase (2007-2010), when the frequency of occurrence of quiet conditions will maximize the opportunity to observe the relatively weak interchange effect. The complementary IMAGE-Cassini study will use our familiarity with the Earth system to guide discovery in the relatively unexplored Saturn system, in effect extending the S^3C Great Observatory to the outer planets.***

A.4 Hot-Cold Plasma Interactions

The overlap between hot and cold plasmas can favor the growth of waves that can alter both the pitch angles and the energies of the hot particles [*Kennel and Petschek*, 1966]. Through wave-particle resonance, pitch-angle scattering causes some particles to be lost into the ionosphere, whereas energy scattering can result in a net acceleration [*Albert*, 2004]. Thus, cold plasma is host to wave-particle interactions that play a major role in the dynamics of the ring current and radiation belts (**S^3C research focus areas F2.1, H2.2, J1.1, J1.2**). ***IMAGE provides the global perspective that is crucial to quantify the total contributions of various energization and loss processes.***

Both ring current ions and radiation belt electrons can be pitch-angle scattered by *electromagnetic ion cyclotron* (EMIC) waves. Global knowledge of the shape and extent of the plasmasphere (especially plumes) is a prerequisite for understanding transport and loss of the ring current, explaining auroral proton precipitation features, and quantifying EMIC wave losses of the radiation belts. For example, pitch-angle scattering of radiation belt electrons by EMIC waves in and near plasmaspheric plumes are a main candidate for why energetic electron fluxes typically drop sharply during the main phase of storms [*Baker et al.*, 2004], but quantification of this effect has been elusive using traditional in situ measurements alone. Predictive models of the radiation belts demand a global model of EMIC wave generation and distribution that is valid both near dusk (***A.4.a***) and dawn (***A.4.b***).

The plasmasphere is typically permeated with a broad-band whistler-mode wave known as *plasmaspheric hiss*, which can pitch-angle scatter radiation belt electrons [*Lyons et al.*, 1972]. *Chorus*, another whistler-mode wave generated by temperature anisotropy in plasma sheet electrons, is believed to be a major energization term for radiation belt electrons [*Albert*, 2004]. Theoretical studies show that chorus energization is most efficient in regions of low plasma density (i.e., outside the plasmapause), and observations show the most dramatic flux increases of the radiation belts occur during storm recovery phase. Thus, global knowledge of the outer extent of the recovery phase plasmasphere is crucial for characterizing both energization by chorus and losses by hiss.

A.4.a. Radiation Belt Losses and Acceleration. IMAGE EUV and RPI observations have played a crucial role in connecting radiation belt losses to wave-particle interactions inside the plasmasphere [*Baker et al.*,, 2004; *Goldstein et al.*, 2005d; *Green et al.*, 2005] (see **Figure 13** in **Section III**). However, there are compelling unanswered questions, ***directly relevant to S^3C research focus areas F2.1 and H2.2, and fundamental to J1.1 and J1.2,*** that will greatly benefit from the global IMAGE and TWINS observations. At the core of this investigation is the ability to determine the global cold plasma distribution (using IMAGE EUV and RPI) and the global ring current distribution (using IMAGE HENA and MENA, and TWINS), allowing us to quantify the time spent by electrons inside regions likely to contain *plasmaspheric hiss* (distributed throughout the plasmasphere), EMIC waves (in the overlap region between the ring current and plasmaspheric plumes), and *chorus* (in the vicinity of, and outside, the plasmapause). Because of the very high energies possessed by radiation belt electrons, it is the integrated effect of passing through regions with these waves that is important; this is just what global imaging can provide, in a way that is difficult or impossible to do with observations with more limited spatial coverage. Therefore, IMAGE and TWINS can and should play a central role in advancing our understanding of this critical region. Science questions to be addressed are: (1) What is the loss rate of radiation belt electrons from (a) *plasmaspheric hiss* and (b) *EMIC* waves? (2) What is the acceleration rate from *chorus*? (3) What are the seasonal, MLT, latitudinal, and geomagnetic activity dependences for chorus and hiss? IMAGE EUV and HENA, along with TWINS, will identify regions of likely wave growth; and chorus and the upper frequency band of hiss can both be directly measured by RPI (in passive mode), supported by modeling of the electron plasma sheet. We can quantify the trapped, energized, and scattered populations using models that rely on wave growth [*Albert*, 2003], in situ particle flux and pitch-angle measurements (NOAA, SAMPEX, GOES, LANL, Polar, HEO), and ground-based balloon campaigns to measure bremsstrahlung radiation from precipitating electrons [*Woodger et al.*, 2005]. ***Understanding obtained during 2007-2010 will be of great benefit to maximizing science gain from the upcoming RBSP mission, and continued global imaging should be an essential part of this effort.***

A.4.b. Subauroral Proton Precipitation. IMAGE studies of the proton aurora have provided evidence for hot ring current and cold plasmaspheric interactions and wave-particle coupling in the Earth's duskside/dayside magnetosphere. *Burch et al.* [2002] showed that duskside *subauroral proton arcs* (discovered by IMAGE [*Immel et al.*, 2002]) appear when IMF B_Y or B_z changes from negative to positive, confirming predictions of IMF-dependent convection and field-aligned current models by *Burch et al.* [1985] and *Cowley et al.* [1991]. *Spasojevic et al.* [2004, 2005b] used FUV, EUV, and Los Alamos in situ data to link the subauroral proton arcs to EMIC waves inside cold plasmaspheric plumes (**see Figure 8**), verifying predictions of the overall mechanism by *Kennel and Petschek* [1966]. The process may be a significant loss mechanism for hot ring current particles. Sub-auroral *proton flashes* [*Hubert et al.*, 2003, 2005; *Zhang et al.*, 2004; *Fuselier et al.*, 2004] are a related phenomenon in which a sudden increase in solar wind dynamic pressure (such as an interplanetary shock) heats ring current plasma colocated with cold plasmaspheric plasma. This burst of heating creates conditions favorable for EMIC wave growth, causing a transient flash of ring current proton precipitation.

New subauroral proton features on the dawnside are less well understood. *Frey et al.*, [2004a] showed that Sub-Auroral Morning Proton Aurora Spots (SAMPS) occur during the recovery phase of geomagnetic storms. Their magnetic latitude is determined by the minimum Dst of the storm. The spots rotate in local time at about 70-95% of the corotation speed. SAMPS map to near the plasmapause (**Figure 9**), suggesting that they are associated with plasmasphere expansion and refilling [*Singh and Horwitz*, 1992; *Sandel et al.*, 2003]. There is also evidence for a statistical enhancement in ion cyclotron waves occurrence on the dawnside [*Anderson et al.,* 1993], suggesting that wave-particle interactions are also responsible for SAMPS. Science questions to be addressed are: (1) Are dawnside spots generated by the same wave-particle interactions that generate duskside arcs and flashes? (2) Does the resonant interaction occur at the dawnside plasmapause or (as *Carpenter et al.*,

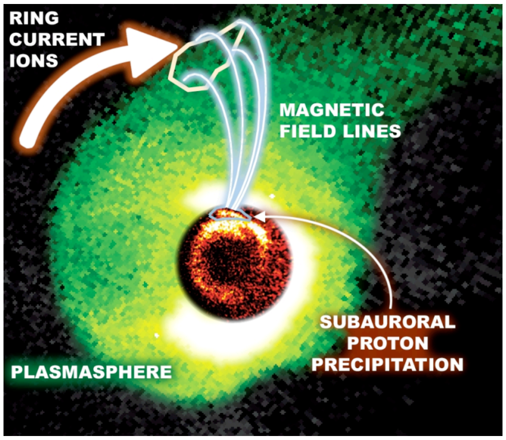


Figure 8. Composite image depicting afternoon-sector subauroral proton precipitation, viewed from above the North magnetic pole. The red pixels (inside the limb of the Earth) show the auroral oval imaged by FUV, with a subauroral detached arc. The green pixels depict the plasmasphere imaged by EUV, showing a drainage plume in the afternoon sector (top of the figure). Ring current ions drift westward and encounter the plume. Hot-cold plasma overlap favors growth of EMIC waves that scatter protons along field lines (blue curved lines).

[2002] suggested) within single flux tubes of increased plasmaspheric density (which might explain the very localized appearance of the SAMPS)? (3) What is the quantitative contribution of SAMPS precipitation to the overall loss rate of the trapped ring current population? (4) What is the quantitative effect of SAMPS-related EMIC waves to the dynamics of energization and loss of radiation belt electrons? ***These science questions address S^3C objectives H2.1, H2.2, F2.2, and F2.4.***

In this investigation, the origin and quantitative significance of the SAMPS and other dawnside phenomena will be studied using combined global imaging (IMAGE and TWINS) and in situ observations. Linking these waves to the precipitation requires simultaneous global images and in situ observations like those used to elucidate the wave-particle interactions on the duskside. Early in the extended mission, IMAGE data will be used in conjunction with plasma data from the Los Alamos spacecraft as well as with precipitating particle, magnetometer, and plasma data from other spacecraft (e.g., DMSP and Polar) that sample the dawnside region. These data will be analyzed and combined with EUV images of the plasmasphere and ENA images (IMAGE and TWINS), to link hot and cold plasma interfaces with the precipitation locations observed by FUV, similar to the work on the duskside by *Spasojevic et al.* [2005b]. Using IMAGE and TWINS together will allow determination of proton pitch angles, allowing quantitative measurement of the protons scattered into the ionosphere. As on the duskside, the dawnside plasma conditions will be analyzed to determine if they are favorable for generation of ion cyclotron waves. Direct observation of the waves and proton precipitation will demonstrate whether the same wave-particle interactions are responsible for both dawnside and duskside subauroral phenomena. ***These simultaneous observations will benefit from the launch of the THEMIS mission, when multiple spacecraft will sample the dawnside region.*** Finally, the extent of loss of dawnside plasma will be quantified by determining the intensity (using in situ observations) and the extent (using FUV imaging) of the proton precipitation. ***The period 2007-2010 (solar minimum and ascending phase) will maximize our opportunity to witness SAMPS during plasmaspheric refilling intervals, as well as to take advantage of continuous or stereo ring current imaging using IMAGE and TWINS together.***

A.5 Remote Sensing of the Heliosphere

Although designed for magnetospheric studies, IMAGE's LENA instrument has been able to observe the neutral component of the solar wind and interstellar neutrals flowing through the heliosphere. (Technology developed for LENA has been applied to the low-energy imager to be flown on the IBEX heliospheric imaging mission.)

Asymmetries observed by LENA in the neutral solar wind and interstellar neutrals have been intepreted as evidence for the unanticipated existence of a secondary stream of interstellar neutrals, offset from the primary interstellar flow direction [*Collier et al.*, 2001; 2004]. This hypothesis is controversial and requires significant additional verification, although a review of relevant literature has identified at least 12 independent data sets that point toward a heliospheric asymmetry in the same sense, several of which are illustrated in **Figure 10**. Further, recent SOHO/Swan and Voyager energetic particles observations have led to independent studies arguing for a similar heliospheric asymmetry [e.g., *Lallement et al.*, The reasons for this apparent asymmetry are still not clear. Inclination of the interstellar magnetic

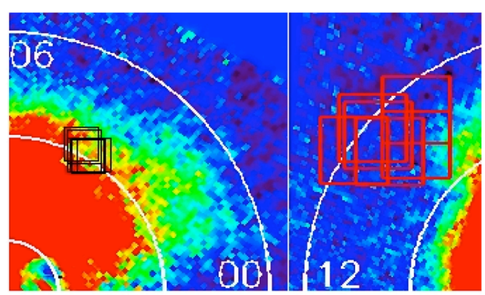


Figure 9. Examples of the relationship between corotating subauroral morning proton spots (SAMPS) and the plasmasphere. The red pixels are the plasmasphere seen from above the north magnetic pole. The two SAMPS (black and red boxes) map to modulations of the plasmapause, indicating that they result from hot-cold plasma interaction [*Frey et al.*, 2004a].

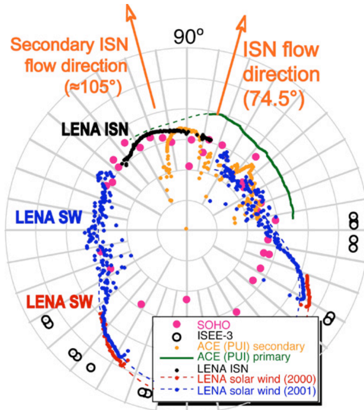


Figure 10. Secondary ISN Flow. A similar asymmetry with respect to the interstellar neutral (ISN) wind direction is found in several different data sets, including LENA neutral solar wind (SW); LENA ISN; ACE pickup-ion (PUI) primary and secondary peaks; ISEE-3 waves; SOHO particles [*Wurz et al.*, 2004; *Collier et al.*, 2004].

field relative to the heliospheric axis and the termination shock is strongly suspected as a possible cause.

During certain intervals, LENA and HENA are able to view the heliosphere from inside the magnetosphere, looking outward in directions where the magnetospheric particle population does not provide high background. This capability provides IMAGE an opportunity to answer the following questions: 1) Is there a time dependence to the ISN secondary stream that can be observed over the course of a solar cycle? and 2) Is the upper limit on energetic neutral atoms from the termination shock different for different view directions? These questions are relevant to ***S^3C focus F3.4, How do the heliosphere and interstellar medium interact?***

A.6 Developing, Improving Models with IMAGE

The advent of global imaging has brought about a profound change to the way models of the inner magnetosphere are developed and validated. Historically, it has been a difficult challenge to reconcile the results of models with (often sparse) single-point measurements. Magnetospheric imaging has the advantage of a systems-level perspective that was previously only found in models, and as such, it provides the contextual information so crucial to proper model validation. For example, after decades of inconclusive comparison with single-point and ground-based observations, the decades-old prediction of an eastward "skewed" ring current peak was finally confirmed [*Burch*, 2005]. An image can contain as many measurements (of a given quantity) as an entire mission's worth of in situ data, and this sheer volume of information feeds back into models, refining their predictive abilities and allowing quantitative treatment of ever more subtle physics. The first plasmasphere images proved the existence of convection-driven plumes [*Sandel et al.*, 2001] and inner magnetospheric overshielding [*Goldstein et al.*, 2002; 2003b]. Five years into the IMAGE mission, we can model the storm-time convective-driven plasmapause location with unprecedented accuracy (0.2-0.7 R_E) [*Goldstein et al.*, 2005a] and are now probing the possible influence of neutral winds and interchange instability, to obtain even greater capability.

The science investigations described in Sections A.1 through A.5 will use IMAGE data to formulate and validate predictive models required to achieve the goals of the S^3C roadmap. For example, assimilation of IMAGE data into radiation belt models (an effort that has just begun) promises to improve dramatically the performance of these models. At any given time, the distribution of radiation belt electrons reflects a complex imbalance between acceleration and loss processes, including critical resonant interactions between electrons and various electromagnetic wave modes. As described in investigation **A.4.a**, quantification of the time-integrated effect of acceleration from *chorus* and losses from *EMIC* and *hiss* can benefit greatly from global knowledge of the plasmapause and ring current, in a way that has been impossible before systems-level imaging. In the science investigations planned for the extended mission, IMAGE data will play an essential role in developing and improving geospace models.

B. IMAGE's Place in the S^3C Great Observatory

NASA's current and future S^3C missions constitute a Great Observatory that provides the multiple perspectives needed to characterize Earth's space environment as a complex, coupled system, driven by the variable input of energy from the Sun, and to understand fully the fundamental physical processes that operate in it. ***IMAGE occupies a unique place within this Great Observatory, now and in the foreseeable future, as NASA's primary tool for global auroral and magnetospheric imaging.*** IMAGE observations of the proton and electron aurora, of the global cold plasma distribution, and of the proton and oxygen ring current and plasma sheet establish a global, macroscopic context for localized in situ studies of discrete magnetospheric regions and phenomena by other Great Observatory assets and are thus central to the goal of achieving a systems-level understanding of the workings of the geospace environment.[1]

During the period 2007-2010, IMAGE support of and/or collaboration with other S^3C missions will lead to an expansion and deepening of our understanding of a) the

[1]"... Sun-Solar System Connection science depends increasingly on combining multi-point *in situ* measurments with remote imaging." NASA, *Sun Solar System Connection: Science and Technology Roadmap 2005-2035*, p. 18, 2005.

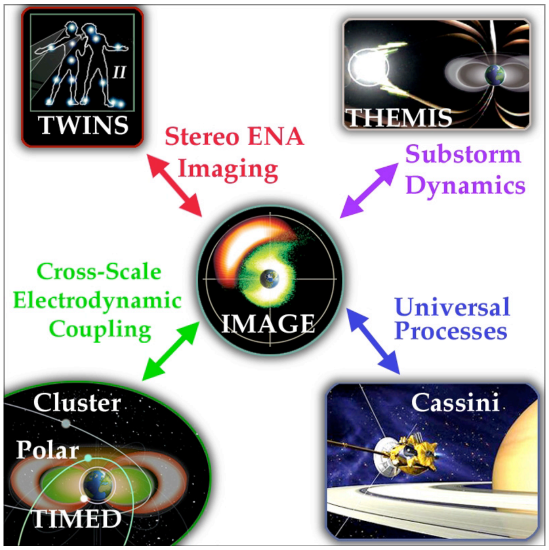


Figure 11. IMAGE: Part of the S³C Great Observatory. IMAGE is the only S³C satellite to obtain a full set of global images of the aurora, plasmasphere, and ring current. In combination with simultaneous in situ observations (THEMIS, Cluster) and other remote-sensing observations (TWINS, TIMED), IMAGE will play a vital role in advancing S³C science objectives.

ring current/plasma sheet through stereo ENA imaging, b) substorm dynamics, c) cross-scale electrodynamic coupling, and d) universal plasma processes (**Figure 11**).

Stereo ENA Imaging. IMAGE HENA and MENA observations will complement the medium-energy ENA observations by two TWINS spacecraft in Molniya orbit. The multiple viewing geometries achieved by the IMAGE-TWINS combination will enable three-dimensional ENA imaging of the ring current/plasma sheet and determination of global ion pressure and pitch-angle distributions in the ring current. Continuous IMAGE/EUV monitoring will provide contextual information on the cold plasma population needed to understand the scattering and loss of the hot plasma observed by TWINS and IMAGE. Prior to the launch of TWINS-2 (in 2006 or later), IMAGE and TWINS-1 (2005 launch) will provide stereoscopic imaging of the inner magnetosphere at least a full year in advance of the deployment of both TWINS spacecraft.

Substorm Dynamics. IMAGE observations will provide a global context for the in situ investigation of substorm initiation and evolution by the 5-spacecraft THEMIS constellation (launch 2006). IMAGE/FUV will provide global images of auroral substorm development, complementing observations by the THEMIS ground-based ASI network, while IMAGE ENA and EUV observations will document the inner magnetosphere's response to substorm plasma injection and magnetic field diplorization (cf. **Figure 7**). IMAGE observations will help THEMIS achieve its scientific goal of resolving the substorm timing controversy, which is one of the major outstanding issues in magnetospheric physics.

Cross-scale Electrodynamic Coupling. IMAGE collaborations with other S³C missions such as Cluster and TIMED (and, when possible, Polar and FAST) as well as with non-NASA assets such as DMSP, LANL, and C/NOFS will allow M-I-T coupling to be studied on a variety of scale sizes. For example, IMAGE HENA and MENA data can be used, together with TWINS, DMSP, and Iridium, to investigate field-aligned currents, while IMAGE observations of low- and mid-latitude ionospheric emissions will provide a global context for TIMED and C/NOFS measurements of the coupled ionosphere-thermosphere system.

Universal Processes. IMAGE observations of Earth's quiescent, corotation-dominated inner magnetosphere during solar minimum will be compared with Cassini in situ and ENA observations of Saturn's corotating inner magnetosphere to investigate universal plasma processes in a rotationally driven plasma system. (Although Cassini is not a Great Observatory mission in the strict sense, it is reasonable to expand the Observatory concept to include it in view of the opportunity that the IMAGE-Cassini conjunction affords for comparative magnetospheric studies.)

STEREO (launch 2006) will provide the first-ever observations of the 3D structure of the fast, earthward-directed CMEs that are responsible for the most intense disturbances of the M-I-T system. Global magnetospheric imaging by IMAGE, together with in situ measurements by other S³C spacecraft, will be needed to relate the magnetospheric response to the CME structures observed by STEREO, leading to advances in our understanding both of the geoeffectiveness of certain types of CME and of M-I-T sysems's response to solar disturbances.

During the period 2007-2010, the overall goal of the IMAGE mission will be the same as during the prime mission and previous extended phases: to understand the global dynamics of the coupled M-I-T system. ***During this new phase of the mission, however, the combination of IMAGE's proven global imaging capabilities with the new measurement capabilities provided by the THEMIS constellation, STEREO, and TWINS will yield a deeper understanding of the geospace environment and, moreover, holds a rich potential for new discoveries.***

While IMAGE's primary focus is on the structure and dynamics of Earth's inner magnetosphere, IMAGE observations of interstellar neutrals will provide a useful complement to heliospheric studies such as those to be carried out by IBEX. (Conversely, IBEX will make observations of geospace that will complement studies using IMAGE.)

C. Relevance to the 2005 S^{3}C Roadmap

IMAGE contributes to every major science objective in the 2005 S^{3}C Roadmap (**Tables 4, 5, and 6**). There is a strong representation in each science objective, with contributions to two-thirds of the research focus areas. The broad contributions result from several important aspects of the IMAGE mission. Among these are:

- IMAGE is the only mission to obtain synoptic global multispectral images of the inner magnetosphere on time scales of a few minutes, which are relevant to the development of magnetospheric substorms and geomagnetic storms and are directly related to the flow of energy and matter in the magnetosphere. Continued

Table 4. IMAGE contributions to the NASA S^{3}C Roadmap.

Scientific Objectives	Research Focus Areas and Associated Investigations	IMAGE Contributions During Extended Mission
F. Open the Frontier to Space Environment Prediction. *Understand the fundamental physical processes of the space environment—from the Sun to Earth, to other planets, and beyond to the interstellar medium.*	**F1: Understand magnetic reconnection as revealed in solar flares, coronal mass ejections, and geospace storms.** *F1.2. What is the magnetic field topology for reconnection and at what size scales does magnetic reconnection occur on the Sun?*	• (FUV) Provide the only global proton precipitation imager, SI-12, ideal for investigating the ionospheric signature of dayside reconnection. • (EUV, ENA) Measure the rate of energy input from reconnection by monitoring the timing of ring current injection and plasmasphere erosion. **Most Relevant Science Investigations** ***A.1.a*** Bursty reconnection. ***A.1.b*** The role of component reconnection. ***A.1.c*** The role of plumes in reconnection.
	F2: Understand the plasma processes that accelerate and transport particles *F2.1. How are charged particles accelerated to high energies?* *F2.2. How are energized particles transported?* *F2.4. How are planetary thermal plasmas accelerated and transported?*	• (ENA) Provide global views of the injection and drift (F2.2) of the energetic ions in the ring current, the seed population for the radiation belts (F2.1). • (EUV,ENA) Provide global views of the plasmasphere and its overlap with the ring current, which are source regions for waves that energize particles or limit energization efficiency (F2.1). • (FUV) Monitor global ion and electron precipitation that limits effectiveness of global energization processes (F2.1, F2.2) • (EUV,RPI) Provide global monitoring of plasmaspheric convection and refilling (F2.4). **Most Relevant Science Investigations** ***A.4.a*** Radiation belt losses and acceleration (F2.1) ***A.4.b*** Subauroral proton precipitation (F2.1, F2.2). ***A.3.a*** Plasmaspheric refilling (F2.4). ***A.3.b*** Ring current transport & loss (F2.2). ***A.3.c*** Substorm plasma transport (F2.2, F2.4). ***A.3.d*** Earth, Saturn magnetospheres (F2.2, F2.4).
	F.3: Understand the role of plasma and neutral interactions in nonlinear coupling of regions throughout the solar system *F3.2. How do energetic particles chemically modify planetary environments?* *F3.3 How do the magnetosphere and the ionosphere-thermosphere (IT) systems interact with each other?* *F3.4 How do the heliosphere and the interstellar medium interact?* *F3.5 How do the neutral environments in planetary and cometary systems affect the global morphology through charge exchange and mass loading processes?*	• Provide continuous global images of ionospheric O$^+$ injection (F3.2), ionospheric outflow (F3.3), auroral precipitation (F3.3), and charge exchange (F3.3). • Continue to lead the investigation of the secondary stream of interstellar neutral atoms (F3.4). • Provide a global measure of M-I-T coupling effects on the plasmasphere, ring current, and auroral ionosphere (F3.3). **Most Relevant Science Investigations** ***A.2.a*** Neutral-wind plasmasphere coupling (F3.3). ***A.2.c*** I-T electrodynamics (F3.2, F3.3). ***A.3.c*** M-I-T coupling during substorms (F3.3). ***A.5*** ISNA secondary stream (F3.4).
	F.4: Understand the creation and variability of magnetic dynamos and how they drive the dynamics of solar, planetary and stellar environments *F4.4 Understand the ionosphere-thermosphere dynamo interaction and its variability.*	• (EUV) Provide the sole global monitor of plasmaspheric subcorotation driven by the ionospheric disturbance dynamo. • Continue to study how energy is transferred to the inner magnetosphere via the solar-wind-driven dynamo. **Most Relevant Science Investigations** ***A.2.a*** Neutral-wind plasmasphere coupling. ***A.1.b*** The role of component reconnection. ***A.3.c*** Transfer of solar wind energy by substorms.

global monitoring of the inner magnetosphere and aurora by IMAGE plays a vital role in efforts to understand, model, and predict space weather.

- IMAGE provides a real-time data link containing its full data set. These data have been used operationally by the NOAA Space Weather Forecast Center and have become a public resource for planning auroral viewing. The use of real-time data for space weather forecasts relates directly to the societal impact of solar variability.
- During the extended mission, when the fuel on Polar has been depleted, IMAGE will become the only spacecraft acquiring nearly continuous global auroral images. In addition, the auroral imaging on IMAGE is immune to "blackouts" caused by solar flare particle events because of its time-delay integration system. Continuous global auroral imaging, especially over substorm timescales (~1 hour) and over longer storm timescales (~days, with brief interruptions during perigee passes) has been shown to be an important component for determining the flow of energy and matter in the magnetosphere.
- IMAGE provides the only images of the global distribution of proton precipitation, including precipitation in the cusp due to magnetic reconnection. The investigation of magnetic reconnection is directly related to the study of fundamental plasma processes.
- IMAGE provides the only platform for global plasmasphere images. Knowledge of the plasmaspheric configuration is critical for the study of acceleration and transport of particles, plasma-neutral interactions, the response of geospace to storms, and development of reliable space weather models.
- IMAGE provides unique global-scale data on plasma injection and transport, which will provide important tests of current and future theories of solar wind, magnetosphere, ionosphere interactions and is directly related to the flow of energy and matter in the magnetosphere.

Table 5. *IMAGE contributions to the NASA S^3C Roadmap (cont'd).*

Science Objectives	Research Focus Areas and Associated Investigations	IMAGE Contributions During Extended Mission
H. Understand the Nature of Our Home in Space. *Understand how human society, technological systems, and the habitability of planets are affected by solar variability and planetary magnetic fields.*	**H2: Determine changes in the Earth's magnetosphere, ionosphere, and upper atmosphere to enable specification, prediction, and mitigation of their effects.**	• (ENA) Provide global images of region-2 field-aligned currents (H2.1, H2.2), ring current pressure (H2.2), and a measure of magnetic distortion that affects the radiation belts (H2.2). • (EUV) Obtain global electric fields from motion of the plasmapause (H2.2). • (EUV, ENA) Help quantify chorus, EMIC and hiss waves that govern radiation belt dynamics (H2.2). • (FUV, EUV) Help determine regions of enhanced ionospheric density that influence the accuracy of GPS determinations (H2.1, H2.2). • (EUV, FUV) Identify neutral wind patterns, augmenting middle/upper atmosphere models (H2.3). • (ENA) Assess the loss of water products (H and O) to space (H3). • (FUV, ENA) Address effects of major drivers of thermosphere (H2.3). **Most Relevant Science Investigations** ***A.2.a*** Neutral-wind-driven E-fields (H2.1). ***A.2.b*** Inner magnetospheric shielding (H2.1). ***A.2.c*** I-T electrodynamics (H2.1, H2.3). ***A.2.d*** Ionospheric conductance effects (H2.1). ***A.3.a*** Plasmaspheric refilling (H2.1, H2.2, H2.3). ***A.3.b*** Ring current transport & loss (H2.2). ***A.3.c*** Substorm electrodynamics (H2.2, H2.3). ***A.3.d*** Interchange electrodynamics (H2.1). ***A.4.a*** Radiation belt evolution (H2.2). ***A.4.b*** Subauroral precipitation (H2.1, H2.2).
	H2.1. What role does the electrodynamic coupling between the ionosphere and the magnetosphere play in determining the response of geospace to solar disturbances?	
	H2.2. How do energetic particle spectra, magnetic and electric fields, and currents evolve in response to solar disturbances?	
	H2.3. How do the coupled middle and upper atmosphere respond to external drivers and with each other?	
	H3: Understand the role of the Sun as an energy source to Earth's atmosphere, and in particular the role of solar variability in driving change.	
	H3.1. How do solar energetic particles influence the chemistry of the atmosphere, including ozone densities?	
	H3.2. What are the dynamical, chemical, and radiative processes that convert and redistribute solar energy and couple atmospheric regions?	
	H3.3. How do long term variations in solar energy output affect Earth's climate?	

Table 6. *IMAGE contributions to the NASA S^3C Roadmap (cont'd).*		
Scientific Objectives	**Research Focus Areas and Associated Investigations**	**IMAGE Contributions During Extended Mission**
J. Safeguard Our Outward Journey. *Maximize the safety and productivity of human and robotic explorers by developing the capacity to predict the extreme and dynamic conditions in space.*	**J1: Characterize the variability, extremes, and boundary conditions of the space environments that will be encountered by human and robotic explorers.** *J1.1. What is the variability and extremes (worst case) of the radiation and space environment that will be encountered by future human and robotic explorers, both in space and on the surface of target bodies?* *J1.2. How does the radiation environment vary as a function of time and position, and how should it be sampled to provide situational awareness for future human explorers?*	• Provide space weather monitoring of the near-Earth space environment through which explorers must pass, and in which staging of exploration will occur (J1.1). • Provide global observations that improve models and fundamental understanding of the acceleration and loss of hazardous particles (J1.2). • Obtain fundamental knowledge of energetic particle physics that is applicable througout the universe (J1). **Most Relevant Science Investigations** ***A.4.a*** Radiation belt dynamics (J1.1, J1.2). ***A.4.b*** Subauroral EMIC wave generation that scatters energetic particles (J1.2). ***A.3.a*** Quantify recovery phase cold plasma critical for radiation belt acceleration (J1.2). ***A.3.b*** Subauroral EMIC wave generation that scatters energetic particles (J1.2).

III. Noteworthy Accomplishments: 2003-2005

During the present phase of the mission, the IMAGE team has built on results obtained during the prime and earlier extended mission phases to deepen our knowledge of the coupled interplanetary-magnetosphere-ionosphere-thermosphere "system of systems."[2] We highlight here six accomplishments of the present mission phase that the IMAGE team considers to be particularly noteworthy.

Quasi-steady Magnetic Reconnection. Observations of proton aurora have provided compelling evidence that reconnection is, under certain conditions, a continuous, quasi-steady process [*Frey et al.*, 2003ba] (**Figure 12**). Although it has been suspected that reconnection could be a continuous process at the magnetopause, solar flares and magnetospheric substorms are highly bursty. In contrast, IMAGE observed the continuous presence of a proton aurora spot while in situ observations from Cluster demonstrated that this spot maps to the reconnection site on the magnetopause [*Phan et al.*, 2003]. With the time and spatial resolution of IMAGE (2 min and ~100 km), this process is observed to proceed continuously for many hours at a time. An important consequence of this result is that solar wind plasma has continuous access to the Earth's magnetosphere, which thus can never be considered a closed system. ***This work stimulated additional investigations and has so far been cited in 12 scientific publications.***

[2]NASA, *S^3C Roadmap*, p. 17, 2005.

Seasonal and Solar-Cycle Changes in AKR. Observations from the RPI instrument, combined with data from the Polar plasma wave instrument (PWI) have uncovered seasonal and solar-cycle changes in Auroral Kilometric Radiation (AKR) [*Green et al.*, 2004a]. The AKR emissions are more intense during the winter than during summer and less intense during solar maximum than solar minimum. The peak intensity in the AKR spectrum is where the density in the auroral zone cavity

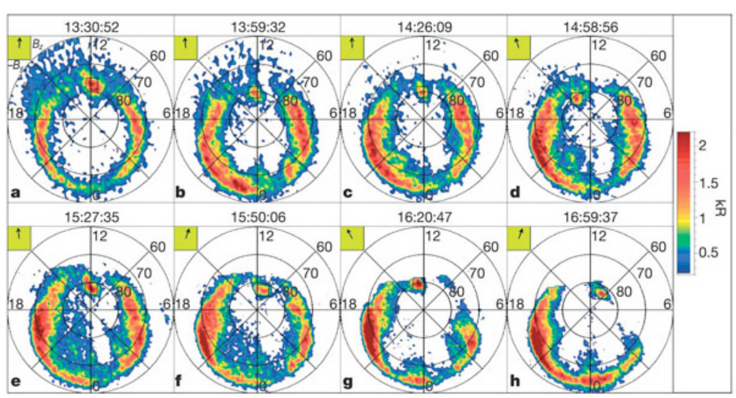


Figure 12. Continuous Reconnection under Conditions of Northward B_z. This series of SI-12 images shows the continuous presence of the ionospheric footprint of the cusp over a 3.5-hour interval during a period of northward B_z and high (~17 nPa) solar wind dynamic pressure (Cluster data not shown). The proton spot shifts in local time in response to fluctuations in B_y. (From *Frey et al.*, 2003a).

is the lowest. The observations support the concept that the expected increases in ionospheric densities (with positive dipole tilt for the northern hemisphere and solar EUV flux increases during solar maximum) play a significant role in magnetosphere-ionosphere coupling by: (1) shortening the altitude range of the auroral plasma cavity, (2) confining the cavity to a smaller range of MLT and closer to midnight, and (3) decreasing the overall intensity of AKR by lessening the density depth of the auroral density cavity. ***The results have important consequences for the use of AKR as a substorm index during different seasons.***

Plasmasphere Control of Radiation Belts. Using IMAGE-EUV and SAMPEX data, it has been confirmed that plasmasphere erosion is a necessary condition for persistent earthward distortion of the Van Allen radiation belts (**Figure 13**). The extremely energetic electrons in the Earth's radiation belts are separated into two belts by a "slot region" devoid of electrons. During geomagnetic storms, the outer radiation belt can expand earthward causing the size of the slot region to decrease. Theoretical and indirect observational evidence has suggested that the inner extent of the outer belt is limited by the presence of the plasmasphere, the home of "hiss" and "EMIC" waves that can scatter the electrons into the ionosphere [*Lyons et al.*, 1972; *O'Brien and Moldwin*, 2003]. Erosion and recovery of the plasmasphere are therefore closely related to inward and outward motion of the outer belt [*Baker et al.*, 2004; *Goldstein et al.*, 2005d]. ***This work has important implications for the development of predictive models of the radiation belts and protection of space assets against radiation damage and was so far cited in 7 related publications.***

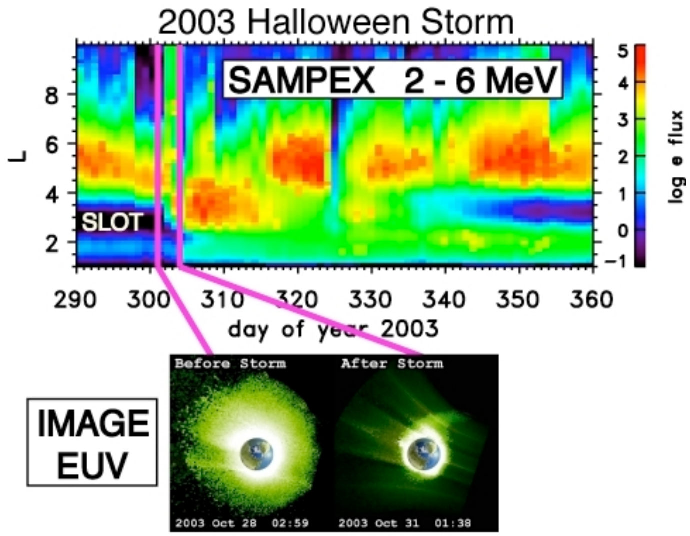


Figure 13. Plasmasphere Control of Radiation Belts. Top: SAMPEX electron data, showing persistent extreme inward distortion of the outer belt that resulted from dramatic decrease of "hiss" radiation inside the plasmasphere. Bottom: IMAGE EUV images of the plasmasphere (mapped to the geomagnetic equator), before and after the great "Halloween Storm" of 2003. The storm caused severe (and almost unprecedented) erosion of the plasmasphere, to under L=2.

Plasmasphere Subcorotation Explained. For decades, all models of inner magnetospheric convection have assumed that in the absence of sunward convection, the plasmasphere strictly corotates with the Earth. IMAGE EUV showed that in fact, the angular velocity of the quiet-time plasmasphere lags corotation by 10-15% [*Sandel et al.*, 2003]. By comparing rotation rates from EUV with ionospheric drifts observed by DMSP spacecraft, *Burch et al.* [2004] showed that plasmaspheric subcorotation is tied to a corresponding lag in the upper ionosphere, caused by ionosphere-thermosphere (I-T) coupling. This result, neither predicted by models nor identified in pre-IMAGE observations, ***has far-reaching consequences for inner magnetospheric modeling***.

Interstellar Neutral Atom Secondary Stream. One of the more startling discoveries from IMAGE has been the asymmetry in the neutral solar wind and interstellar neutral atom stream observed in the LENA data [*Collier et al.*, 2001, 2004; *Pilkerton et al.*, 2005]. At least 12 independent data sets, including SOHO/Swan and Voyager observations, all point to a heliospheric asymmetry in the same sense [*Lallement et al.*, 2005]. The reasons for the asymmetry are still not entirely clear; however an effect associated with the interstellar magnetic field is strongly suspected. *Wurz et al.* [2004] suggest that the LENA observations are consistent with a second stream that consists of energetic (~1 keV) hydrogen associated with the termination shock. LENA observes the second energetic stream every year, peaking in early January. Current (Voyager) and future (IBEX) missions may confirm this new interpretation of the solar wind interaction with the interstellar medium. ***These results are important for our understanding of the development of our galaxy and have been cited in 13 additional publications.***

Quantitative Validation of the New Imaging Techniques. Over the past several years members of the IMAGE team and others have devoted significant effort to the quantitative validation of IMAGE's imaging techniques and to the inversion of observations into quantitative plasma properties. Quantitative validation of the relatively new global images has been performed by comparison with simultaneous in situ data from several observatories, including Cluster, Polar, FAST, LANL, ground-to-GPS TEC, and ground-based magnetometer arrays [*Vallat et al*., 2004; *Moore et al*., 2003; *Fuselier et al*., 2005b; *Moldwin et al*., 2003; *Clilverd et al*., 2003; *Dent et al*., 2003; *Goldstein et al*., 2004b]. In addition to the primary images, IMAGE provides level 2 analysis images such as global maps of 3D field-aligned currents from HENA [*Roelof et al.,* 2004], plasmapause electric field and mass loss rates from EUV [*Goldstein et al*., 2005c; *Foster et al*., 2005; *Spasojevic et al*., 2003b], ionospheric conductivity and precipitation energy and energy flux from FUV [*Frey et al*., 2003c], magnetopause motion and solar wind density from LENA [*Collier et al*., 2005; *Pilkerton et al*., 2005], ion outflow estimates from LENA [*Moore et al.,* 2003], plasma density distribution along flux tubes from RPI [*Huang et al.,* 2004], and ion temperature maps from MENA and HENA [*Scime et al*., 2005; *Zhang et al*., 2005].

Additional accomplishments during the present mission phase include the following:

IMAGE has characterized and explained localized auroral emissions not associated with the main oval. These include Sub-Auroral Morning Proton Spots (SAMPS), which occur during the recovery phase of geomagnetic storms [*Frey et al*., 2004a], and localized HiLDA (High Latitude Dayside Aurora) emissions inside the polar cap that occur in summer under conditions of positive B_y and low solar wind density [*Frey et al*., 2003b; *Korth et al*., 2004].

RPI observations combined with data from the Plasma Wave Instrument on the DE-1 spacecraft have demonstrated that plasmaspheric hiss can be mapped to regions of lightning [Green et al., 2005]. These observations strongly support lightning as the dominant source for plasmaspheric hiss, which through particle-wave interactions, maintains the slot region.

IMAGE has discovered a link between the ring current and the thermosphere. Simultaneous HENA and FUV measurements have revealed that oxygen ENAs created in the ring current during magnetic storms precipitate directly into the mid-latitude upper atmosphere [*DeMajistre et al*., 2005].

IMAGE has explained a 33-year old puzzle: why do isolated substorms produce only temporary inward motion of the plasmapause? Isolated substorms, thought to bring enhanced convection that causes erosion, were found (in ground-based whistler studies) to cause only temporary plasmapause distortion [*Carpenter et al*., 1972]. EUV images reveal that only sustained southward IMF leads to erosion [*Goldstein and Sandel*, 2005]. Isolated substorms bring only a temporary global impulse caused by geomagnetic dipolarization [*Goldstein et al*., 2004a; *Goldstein et al*., 2005b].

Correlative studies of conjugate auroras using IMAGE FUV and Polar observations have revealed surprising morphological differences between the aurora borealis and the aurora australis, including non-conjugate theta auroras [*Østgaard et al*., 2003], displacement of auroral features by up to 1.5 hours in MLT from magnetically conjugate locations [*Østgaard et al*., 2004], and multiple bright spots in the southern aurora mapping to unstructured auroral luminosity in the northern oval [*Fillingim et al*., 2005]

FUV and EUV observations in conjunction with LANL geosynchronous data have linked subauroral proton arcs to plasmaspheric drainage plumes and verified the mechanism responsible for the proton precipitation [Spasojevic et al., 2004; 2005b]. Subauroral proton arcs (discovered with the FUV/SI-12 instrument during the prime mission [*Immel et al*., 2002]) result from resonant scattering of protons by EMIC waves that are enhanced by the interaction of the cold, dense plasmaspheric material with hot ring current ions.

IMAGE observations of OI 135.6 emissions have been used, alone and in conjunction with TEC, TIMED/GUVI, and ROCSAT 1 data, to study the dynamics of the low- and mid-latitude ionosphere and thermosphere. FUV data have shown 1) that magnetic storms redistribute plasma from the low-latitude equatorial ionosphere into the polar caps [*Immel et al*., 2005; *Foster et al*., 2005]; 2) that zonal plasma drift speeds are unambiguously associated with Dst [*Immel et al*., 2004]; 3) that atmospheric gravity waves play an important role both in initiating equatorial plasma bubbles and in maintaining their horizontal motion [*Lin et al*., 2005]; and 4) that O/N_2 depletions during negative ionospheric storms corotate with the Earth [*Zhang et al*., 2003; 2004].

IV. IMAGE in the Public Eye

Media and Public Outreach. IMAGE continues to be a major player in keeping S^3C science in the public eye through media outreach. In 2002, IMAGE was the first geospace mission to hold a Space Science Update (SSU), "Earth's Space Storm Shield Offers Protection at a Price." Since then, IMAGE science has been profiled in two further SSUs:

- "Stormy Space Weather Slips Through the Cracks" (December 3, 2003), presented in conjunction with the publication in *Nature* [*Frey et al*., 2003a] of a joint IMAGE/FUV-Cluster result on high-latitude reconnection
- "IMAGE Discovers Cause of Unusual Van Allen Belt Distortions" (December 15, 2004), a joint SSU/press conference on the discovery, reported in *Nature* [*Baker et al*., 2004], of the link between plasmaspheric erosion and the shrinkage of the slot

region and the associated Earthward movement of the outer radiation belt during a major magnetic storm.

IMAGE has had eleven press releases since launch, generating over one hundred newspaper articles (http://image.gsfc.nasa.gov/press_release/) and stories in magazines such as *Science News, Physics News,* and *Scientific American*. ("The Fury of Space Storms," an article on geomagnetic storms featuring IMAGE and IMAGE data on the Bastille Day Storm, was selected for republication in a special issue of *Scientific American* published in 2004. The article originally appeared in April 2001.) (More information on IMAGE's E/PO activities can be found in Section VI.)

V. Technical and Budget

A. IMAGE Technical Status as of 30 September 2005

A.1 Instruments

After 5.5 years of operation, all of the IMAGE instruments continue to perform nominally. The technical status of each instrument is summarized below.

FUV. The IMAGE FUV instrument is operating nominally and its performance is better than expected from predictions of its design lifetime of nominal two years. As expected over the past 5 years the microchannel plates (MCP) lost some of their efficiency and to compensate gain loss the high voltage (HV) has been raised. Over the past two years an increased sensitivity for longer wavelength photons was observed (red leak), most likely caused by electronic traps within the band gap of the photocathode. This manifests itself as an increased response to the sunlit regions. This is not a problem for the analysis of auroral observations in the dark sector. However, when the aurora is sunlit, it requires more efforts for the proper dayglow removal. The SI channels continue to show their larger-than-expected temperature response. A combination of high voltage and pulse acceptance threshold adjustments was used to maintain a reasonable sensitivity level. Remaining sensitivity changes are corrected in the ground data analysis software by weekly monitoring of the full instrument response to stars. The GEO channels showed very small sensitivity changes, and their high voltage has only been raised once since launch. A full summary of all instrument operations is published at http://sprg.ssl.berkeley.edu/image/.

EUV. The performance of EUV has been nominal since its first turn-on. The version of the flight software loaded when the instrument was delivered is still in use. The sensitivity of EUV has been stable in flight. We monitor the sensitivity by observing the Moon, a relatively bright and stable source of reflected sunlight at 30.4 nm. These observations are the best available measure of end-to-end performance. After accounting for variations in the solar flux at 30.4 nm, we find no evidence for a change in sensitivity. We have adjusted the high voltage to the MCP detectors to keep their gains within the acceptable range. We monitor the gains of the MCPs by measuring their pulse-height distributions continuously. As expected, the gains at a constant voltage have decreased slightly with time. In September 2000, July 2002, and July 2003, we increased the high voltage to the detectors to compensate for this drop in gain. We anticipate another increase in October 2005. Because the modal gain is much higher than the counting threshold, the changes in gain were not reflected in variations in sensitivity. At the present rate of gain decay, the HVPS has reserve capacity sufficient for many years of normal operation. Apart from these planned changes, the output of the HVPS has been stable, and free of secular drifts. In late January 2003 we detected an increased response to scattered light in EUV's center camera under some conditions. At the same time, that camera began responding to a few of the brightest stars in the FUV spectral range. The most likely explanation is the formation of a hole in the entrance filter. Using the known flux from the detected stars, we estimate the diameter of the hole to be ~100 microns. The effect of the hole is to increase the background when the EUV field is near the Sun. In February 2004 a hole of similar size appeared in the filter of one of the other two cameras. The increased background does not interfere with the operation of the camera or affect the usefulness of the images of the plasmasphere.

HENA. The HENA imager continues to function nominally, and is returning high quality data on the Earth's ring current for each geomagnetic storm that occurs. The HENA instrument has microchannel plate (MCP) detectors that were built to a relatively new (at the time) design that extends their useful life far beyond that of earlier such detectors. These Long-Life MCPs (by Galileo Electro-Optics, now Burle) have performed extremely well since commissioning. We raised the bias high-voltage to accommodate gain degradation several times early in the mission, but the plates seem to have plateaued, and further voltage increases have not been required for about the last two years. We know of no life-limiting aspect of the HENA design other than eventual radiation damage from accumulated dose. There has been no indication of damage to date, and we expect many more years of high quality data from this instrument.

MENA. The MENA imager continues to function normally. All three sensor heads provide full imaging capabilities, continuously returning image data of the inner magnetosphere and the near- to mid-region plasma sheet.

The microchannel plate (MCP) detectors on MENA have been operated at the same bias voltage for the past 2.5 years. We routinely monitor MCP performance in order to be able to react to possible future gain degredation by raising the bias voltage. From data acquired throughout the mission we conclude that MENA MCPs have at least 80% of their life-time remaining; no MCP life-time issues should arise even for a significantly extended mission. The Sensor 1 collimator, which had shown voltage degradation earlier in the mission, has now stabilized. In-flight testing of the effect of collimator voltages on instrument performance has shown that, aside from a slightly increased noise level, the Sensor 1 collimator has not only had no negative impact on the instrument performance, but that we also expect no negative impact for future years. MENA employs three identical sensors with overlapping fields-of-view, and if necessary a reconfiguration into a two-sensor mode (identical to the operations of TWINS) is possible through simple commanding of the instrument.

LENA. LENA lost one of four position sensing signal preamplifiers in September 2000, but a ground software workaround restored much of its imaging capability. It lost one half of its bipolar charge particle rejecting collimator system through sputtering of metals onto insulators by radiation belt particles. This has reduced the effectiveness of the charged particle deflection, but it remains effective in most environments. The LENA detector sensitivity has decayed somewhat, but has been restored to within a factor of two of its original value by raising detector bias. A routine program of quarterly updates has been instituted to assure full and continuous sensitivity. Ample detector reserve exists to support this program for the foreseeable life of the mission.

RPI. The performance of RPI has been nominal since it was first turned on with the exception of losing a redundant transmitter on May 8, 2000. RPI has suffered 6 single event upsets with the instrument always returning to its nominal state after being reset. RPI uses 6 antenna elements in a 3-axis orthogonal configuration feeding 3 receivers. The X and Y-axis antennas, originally extended to 500 m tip-to-tip have suffered debris collisions with the –X antenna losing ~130 m on October 3, 2000, the +Y axis antenna losing a small part of the antenna (possibly only the tip mass) on September 18, 2001, and a larger section of significant but unknown length of +Y on September 30, 2004. The 20 m Z-axis antennas have remained unaffected. Currently RPI transmits with full power on the +X antenna, and partial power on the –X antenna, and receives on all antenna elements.

A.2 Spacecraft

The spacecraft systems continue to function well. The GSFC Flight Operations Team has derived a work-around to correct the Mass Memory Module (MMM) overwrite problem which continues to occur every few months. The work-around involves on/off cycling of the MMM every pass when the problem occurs. The lost data are recovered from the real-time data, which are held on line until reception of the store-and-forward data is verified. A southern-hemisphere station has been established at the University of South Australia to receive the real-time data as apogee precesses over the south pole.

The attitude control system is responding very well and keeping the spacecraft within its attitude requirements despite the asymmetrical loss of RPI wire antennas. As from the first year, the AST is not functional during the summer months when its FOV is close to the Sun, but the Sun Sensor continues to provide reliable data during this period. We also run the torque rod in self-heat mode each winter to prevent its going to a temperature lower than its rated minimum.

The EPS system continues to supply power above its design specifications, enabling us to remain power-positive during the eclipse. The array supplies approximately 12.5 Amps fully loaded, which is enough to run the spacecraft, payload and a fraction of the heaters simultaneously, or to run the spacecraft, payload heaters, and simultaneously charge the battery from 40% to full state of charge (SOC) in less than 10 hours. The battery continues to maintain the bus in the specified voltage range down to a calculated SOC of 40% with the spacecraft systems all running (except the AST).

The communications system has performed flawlessly, enabling us to establish downlink and uplink with 26-m DSN antennas, which provide greater flexibility than the 34-m antennas for which the system was designed.

The thermal system continues to be very efficient at dissipating heat from the payload and spacecraft systems. Although we anticipate degradation of the system as the thermal surfaces weather, this will actually be something of a relief as most of thermal-control challenges we have seen so far have been near the cold end of the scale (as detailed above).

Performance of the power subsystems and battery remains nominal with a large power margin. One item of concern is the switchover from the A-side power supply to the backup B-side supply, which occurred on 2005/02/01. The cause of this switchover could not be definitively determined, because it occurred when out of real-time contact with IMAGE and because the CPU reboot it induced erased the MMM. All power parameters were nominal during the prior pass. LMMS Engineers have told us that there is no way to verify the health of the A-side power supply short of forcing another CPU reboot and watching if it comes up on the A or B side.

The spacecraft continues to deal with the impact on spin-balance of the loss of parts of the RPI radial antennas, which results in a coning of the spin axis. The coning of the IMAGE spin-axis caused extra problems this year, as the coning sometimes took the Sun out the the FOV of the Sun Sensor during some spins when the AST was off line. This situation introduced errors in the nadir pulse times the instruments use for syncronization. The instruments most affected were FUV, because of its narrow field of view, and EUV because it takes data over multiple spins. This situation has now been resolved as the Sun is back within the FOV of the sun sensor.

No problems are apparent that would prevent continued operation of the IMAGE observatory for the foreseeable future. The final limit to operability will likely be solar cell degradation, but at the current rate that will not impinge on instrument operations for at least another 10 years during most seasons. Extreme conditions (eclipse operations, cold season) may be an exception to this, but that depends on the competing degradation of the solar arrays (which supply heater power) and the thermal control coatings (which remove heat).

B. Data Availability and Dissemination

B.1 The IMAGE Data System

IMAGE is the first space physics mission for which there are no proprietary data periods. The SMOC maintains approximately two weeks of all the latest IMAGE data and browse products on line from all the instruments [*Burley et al*., 2000]. (The URLs for this and other web sites from which IMAGE data tools can be accessed are listed in **Table 7**). The SMOC generates the high-resolution Level-0.5 IMAGE science data in the Universal Data Format (UDF). Specialized software developed for analyzing the UDF data enables users to apply the latest instrument calibration and to intercompare data from all the IMAGE instruments.

Within 48 hours of being received by DSN and processed at the SMOC, all IMAGE data are transferred to the NSSDC for long-term archiving. To facilitate community access to the IMAGE data, the NSSDC has loaded the UDF data files into their FTP on-line disk storage area (**Table 7**) providing "around the clock" access to the data. With the SMOC (latest IMAGE data), the NSSDC (older archival data), and CDAWeb (browse science and engineering data), IMAGE data products are easily available to the entire international science community. The NASA data availability catalog provides the archiving status of the IMAGE data.

The IMAGE Software Suite (ISS), comprising a variety of specialized IMAGE software utilizing Java and IDL, can be downloaded from the on-line IMAGE Software Archive (**Table 7**). For UDF, ISS supports Windows, Apple/Macintosh (OS X), and Linux/Unix platforms. In addition to its availability on the web, ISS has been distributed on CD-ROM at a number of AGU meetings. The CD-ROM contains all the software in the form of installation packages.

B.2 Distribution of IMAGE Data by Individual Instrument Teams

Each IMAGE instrument team maintains a web site with a variety of freely available data products (e.g., custom plots/images, quick-look/survey data, movies, and 24-hour plots). In addition, these sites provide documentation and instrument-specific data analysis tools. The individual instrument sites are all accessible from the Image Science Center (http://image.gsfc.nasa.gov) and are multiply interlinked so that visitors to one site can easily access other IMAGE instrument sites.

EUV. The primary EUV image analysis tool, *euv_imtool*, is available at the EUV web site (**Table 7**). This IDL-based tool retrieves data from the UDF database and can be used on Windows, Mac, and Unix/Linux platforms. *euv_imtool* also reads image files in Flexible Image Transfer System (FITS) format. A page on the EUV website can be used to request FITS files from the UDF database. Requests are processed automatically and the resulting FITS files stored for retrieval by FTP. Other data products are available at the EUV website, including selected single frames and more than 2500 movies, each made up of frames from a single IMAGE orbit. Currently there are 53 University users

Table 7. Availability of IMAGE Data on the Web

Site	URL
IMAGE SMOC	http://150.144.211.77/image/image_main.html.
NSSDC	ftp://nssdcftp.gsfc.nasa.gov
IMAGE Software	http://image.msfc.nasa.gov/
EUV	http://euv.lpl.arizona.edu/euv
FUV	http://sprg.ssl.berkeley.edu/image/
HENA	http://sd-www.jhuapl.edu/IMAGE/
LENA	http://lena.gsfc.nasa.gov
MENA	http://pollux.space.swri.edu
RPI (GSFC)	http://image.gsfc.nasa.gov/rpi/spectrogram
RPI (UMass)	http://ulcar.uml.edu/framesRPI.htm

from 27 different institutions, 10 government users from 5 unique institutions, and 18 company (.com) users from 8 institutions.

FUV. The FUV web site (**Table 7**) provides thumbnail-sized summary WIC images for almost the entire IMAGE mission. (The first date for which summary images are available is 18 May 2000.) In addition, the site now offers a web tool that allows anyone to access all of the data from all three imaging channels. Users can scale the images by adjusting the dynamic range and color table of the image. This option allows any scientist to generate publication-quality images directly from the FUV web site by running a Java program on the FUV team's server. Since the 2003 Senior Review, the FUV web server has been accessed from 1700 individual IP addresses and 26475 images (individual FUV times, with a raw image and a mapped image) have been requested. There have been 676 requests for more than 10 images and 166 requests for more than 100. The FUV image display and manipulation software is freely available and is currently used by 20 groups in the U.S., Canada, Japan, Belgium, Norway, Sweden, UK, and Italy extending access of FUV data well beyond the IMAGE team.

HENA. A wide variety of HENA browse products as well as a web-based data display tool are available at the HENA web site (**Table 7**). XHENA, the web-based display tool, uses the same (fully documented) software that the HENA team uses for its custom viewing of HENA images and allows researchers to access HENA data without needing to request data from the HENA team. Since the last Senior Review an average of 20 GB/month of HENA data have been distributed through this web site to several hundred users.

MENA. The MENA web site (**Table 7**) provides a web-based image making tool, the MENA Image Making Engine (MIME), which allows users to make both custom images and movies. The MENA web site also makes available pre-processed 24-hour summary plots of science and housekeeping data. All MENA software uses UDF data as input and is written in IDL, giving access to MENA data on all platforms on which IDL and UDF can be installed (Unix/ Linux/ Windows/ Mac OS X). The MENA image making software is currently being used routinely at the University of West Virginia, Auburn University, and the Rutherford Appleton Lab in the UK. Since the last Senior Review MENA summary plots have been accessed over 21,000 times. Currently there are 46 University users from 35 different institutions, 17 government users from 4 unique institutions, and 14 company (.com) users from 18 institutions.

LENA. The LENA primary analysis software is available at the LENA web site (**Table 7**) It is IDL-based and can be used on Windows, Mac, and Unix/Linux platforms. For those who prefer not to install the UDF software and data files, the LENA data server also provides a web-form-driven interface to the LENA software. The Custom Plots page on the LENA web site can be used to select from a wide variety of plot styles and to choose an arbitrary time interval. Requests are processed automatically, and the resulting plots and corresponding text data files are presented in a script-driven web page, made available for download in various formats, and stored on disk temporarily for retrieval by FTP. Many other data products are available at the LENA website, including standard summary plots in a number of different formats for all the data that have been acquired.

RPI. RPIAnywhere, the RPI software suite, can be downloaded from the RPI web site (**Table 7**). An expert database for cataloging and characterizing RPI echoes in the plasmagrams can also be accessed from the RPI web site. Currently, there are 150 individual users from 51 institutions who are using the RPI software suite. Daily spectrograms and plasmagrams are available at the RPI site, and an on-line archive of daily spectrograms is maintained at the IMAGE Science Center (**Table 7**).

B.3 Real-time Data Dissemination

The IMAGE spacecraft has a real-time link designed to provide the full data set to NOAA and to any other group capable of receiving the telemetry. NASA has an MOU with NOAA's Space Environment Center (SEC) to provide real-time data necessary to support their operational space weather forecasting needs. NOAA's ground antenna at Fairbanks, Alaska is their main tracking location. In addition to NOAA, the Communication Research Laboratory (CRL) in Japan captured IMAGE real-time data for their space weather forecasting in Japan (see http://www2.crl.go.jp/uk/uk223/IMAGE/index.html).

Owing to the IMAGE orbit precession, NOAA and CRL have temporally stopped real-time data acquisition of IMAGE but will resume when its apogee returns to the northern hemisphere in late 2007 or early 2008. While apogee is in the southern hemisphere, University of South Australia, Adelaide is performing real-time tracking of IMAGE.

B.4. IMAGE as Part of the S^3C Data Environment

The IMAGE team is eager to become part of the newly emerging S^3C distributed data environment. We expect that we will both participate and contribute to this new data systems approach. In particular, the IMAGE team will work with the Virtual Magnetospheric Observatory (VMO) if it is approved as part of the current "Virtual Observatory" or VO call for proposals. The main efforts involved will be producing a SPASE-Data-Model-based Application Programmer Interface to allow IMAGE data to be machine-accessible in a way consistent with others, and develop services for browsing and analysis of data that can also be accessed as Web Services in the new VO framework. The overall goal of our effort will be to make IMAGE data transparently available through the web services of the VO, which should provide the best possible environment for facilitating multi-mission data comparison and analysis while enhancing the integration of IMAGE with other existing S^3C mission data.

C. Budget

C.1 In-Guide Scenario

The in-guide budget scenario will allow the IMAGE team to continue operating the spacecraft, responding to anomalies, commanding the instruments, processing and archiving the data, and responding to community requests for data, while still managing to achieve a minimum level of meaningful science return. However, in view of the high scientific productivity of IMAGE and the excellent status of the spacecraft and instruments, the in-guide budget falls far short of providing the resources necessary to achieve the full scientific return of the mission. Of particular concern is the difficulty in responding to the many requests for data from guest investigators and collaborators from other missions. Were the budget to be cut below the in-guide level, very little science could be done, and very little support to the community of guest investigators and collaborators from other missions would be possible. The budget would be largely committed to operating the spacecraft, monitoring the health of the instruments, and processing and archiving data. Since graduate students can scarcely be supported with such an activity, the support of the various co-investigator universities would be in serious jeopardy. Thus we feel that the in-guide scenario represents a bare-bones level below which the mission would not be viable.

C.2 Requested/Optimal Scenario

We are submitting a requested/optimal budget for FY 07-10 with a funding level increased by $800k/yr above the in-guide scenario. Although there will be no increase for inflation, a budget at this level will allow IMAGE to continue its core activities, support well the community of guest investigators and collaborators from other missions, and achieve a significant level of meaningful science results. Specifically the additional funds will be used to support (1) post-doctoral scientists with specific responsibilities for interacting with guest investigators and collaborators from the other S^3C Great Observatory missions and (2) graduate students with thesis projects stemming from collaborative efforts between IMAGE other Great Observatory missions. These additional resources will be concentrated at the co-investigator sites experiencing the highest level of data requests, i.e., U. C. Berkeley, the Univ. of Arizona, and Johns Hopkins University Applied Physics Laboratory.

D. References

Adrian, M. L., D. L. Gallagher, and L. A. Avanov, IMAGE EUV observation of radially bifurcated plasmaspheric features: First observations of a possible standing ULF waveform in the inner magnetosphere, *J. Geophys. Res.*, *109*, A01, 203, doi: 10.1029/2004JA009974, 2004.

Albert, J. M., Evaluation of quasi-linear diffusion coefficients for emic waves in a multispecies plasma, *J. Geophys. Res.*, *108*(A6), 1249, doi:10.1029/2002JA009792, 2003.

Albert, J. M., Using quasi-linear diffusion to model acceleration and loss from waveparticle interactions, *Space Weather*, *2*, S09S03, doi:10.1029/2004SW000069, 2004.

Anderson, B. J., Statistical study of Pc 3-5 pulsations and their relevance for possible source mechanisms of ULF waves, *Ann. Geophys.*, *11*, 128, 1993.

Andre, N., M. et al., Multi-instrumental case study of interchanging flux tubes within the Saturnian inner magnetospheric regions, *2005 EGU Meeting*, Abstract EGU05-A-08731, 2005.

Baker, D. N., et al., An extreme distortion of the Van Allen belt arising from the 'Halloween' solar storm in 2003, *Nature*, *432*, 878, doi:10.1038/nature03116, 2004.

Berchem, J., et al., Dayside proton aurora: comparisons between global mhd simulations and image observations, *Space Sci. Rev., 109,* 313, 2003.

Bobra et al., M. G., On the solar wind control of cusp aurora during northward IMF, *Geophys. Res. Lett., 31*, doi:10.1029/2003GL018,417, 2004.

Brandt, P. C., et al., Global ENA observations of the storm mainphase ring current: Implications for skewed electric fields in the inner magnetosphere, *Geophys. Res. Lett., 29(20)*, 1954, doi:10.1029/2002GL015160, 2002.

Brandt, P. C., et al., IMAGE/HENA: pressure and current distributions during the 1 October 2002 storm, *Adv. Space Res., 33(5)*, 719, 2004.

Burch, J. L., Magnetospheric imaging: Promise to reality, *Rev. Geophys., 43(3)*, RG3001, 10.1029/2004RG000160, 2005.

Burch, J. L., P. H. Reiff, and J. D. Menietti, IMF By-dependent plasma-flow and Birkeland currents in the dayside magnetosphere: 1. Dynamics Explorer observations, *J. Geophys. Res., 90,* 1577, 1985.

Burch, J. L., et al., Views of Earth's magnetosphere with the IMAGE satellite, *Science, 291*, 619, 2001a.

Burch, J. L., et al., Global dynamics of the plasmasphere and ring current during magnetic storms, *Geophys. Res. Lett., 28*, 1159, 2001b.

Burch, J. L., et al., Interplanetary magnetic field control of afternoon-sector detached proton auroral arcs, *J.*

Geophys. Res., 107, 1251, doi:10.1029/2001JA007554, 2002.

Burch, J. L., J. Goldstein, and B. R. Sandel, Cause of plasmasphere corotation lag, *Geophys. Res. Lett., 31*, L05, 802, doi:10.1029/2003GL019164, 2004.

Burch, J. L., et al., Properties of local plasma injections in Saturn's magnetosphere, *Geophys. Res. Lett., 32*, L14S02, doi:10.1029/2003GL019164, 2005.

Burley, R. J., S. E. Coyle, and J. L. Green, The IMAGE science and mission operations center, *Space Sci. Rev., 91*, 483, 2000.

Carpenter, D. L., et al., Magnetospheric electric fields deduced from drifting whistler paths, *J. Geophys. Res., 77*, 2819, 1972.

Carpenter, D. L., et al., Small-scale field-aligned plasmaspheric density structures inferred from the Radio Plasma Imager on IMAGE, *J. Geophys. Res., 107,* 1258, doi:10.1029/ 2001JA009199, 2002.

Chandler, M. O., and T. E. Moore, Observations of the geopause at the equatorial magnetopause: Density and temperature, *Geophys. Res. Lett., 30*, 1869, doi: 10.1029/2003GL017611, 2003.

Clilverd, M. A., In situ and ground-based intercalibration measurements of plasma density at L=2.5, *J. Geophys. Res., 108*, 1365, doi:10.1029/2003JA009866, 2003.

Collier, M. R., et al., Observations of neutral atoms from the solar wind, *J. Geophys. Res., 106,* 24,893, 2001.

Collier, M. R., et al., An unexplained 10-40 degree shift in the location of some diverse neutral atom data at 1 AU, *Adv. Space Res., 34*, 166, 2004.

Collier, M. R., et al., Low energy neutral atom signatures of magnetopause motion in response to southward Bz, *J. Geophys. Res., 110*, A02,102, doi:10.1029/2004JA010626, 2005.

Cowley, S. W. H., et al., Dependence of convective flows and particle precipitation in the high-latitude dayside ionosphere on the X and Y components of the interplanetary magnetic field, *J. Geophys. Res., 96,* 5557, 1991.

Craven, J.D., et al., Variations in the fuv dayglow after intense auroral activity, *Geophys. Res. Lett., 21(25),* 2793, doi:10.1029/94GL02458, 1994.

DeMajistre, R., et al., Storm-time enhancement of mid-latitude ultraviolet emissions due to energetic neutral atom precipitation, *Geophys. Res. Lett., 32*, L15,105, doi: 10.1029/2005GL023059, 2005.

Dent, Z. C., et al., A coordinated ground-based and IMAGE satellite study of quiet-time plasmaspheric density profiles, *Geophys. Res. Lett., 30(12),* 1600, doi:10.1029/2003GL016946, 2003.

Dent, Z. C., et al., Plasmaspheric depletion, refilling and plasmapause dynamics: A coordinated ground-based and IMAGE satellite study, *J. Geophys. Res.*, doi:10.1029/2003GL016946, submitted, 2005.

Fillingim, M. O., et al., Hemispheric asymmetry of the afternoon electron aurora, *Geophys. Res. Lett., 32*, L03,113, doi: 10.1029/2004GL021635, 2005.

Fok, M.-C., et al., Global ENA IMAGE simulations, *Space Sci. Rev., 109*, 77, 2003.

Fok, M.-C., et al., Geospace storm processes coupling the ring current, radiation belt and plasmasphere, in *Inner Magnetosphere Interactions: New Perspectives from Imaging*,edited by J.L.Burch, M.Schulz, and H. Spence, American Geophysical Union, Washington, D. C., 2005.

Foster, J. C., P. J. Erickson, A. J. Coster, and J. Goldstein, Ionospheric signatures of plasmaspheric tails, *Geophys. Res. Lett., 29(13)*, 1623, doi:10.1029/2002GL015067, 2002.

Foster, J. C., et al., Redistribution of the stormtime ionosphere and the formation of the plasmaspheric bulge, in *Inner Magnetosphere Interactions: New Perspectives from Imaging*, edited by J. L. Burch, M. Schulz, and H. Spence, American Geophysical Union, Washington, D. C., 2005.

Fraser, B. J., et al., Heavy ion mass loading of the geomagnetic field near the plasmapause and ULF wave implications, in *Inner Magnetosphere Interactions: New Perspectives from Imaging*, edited by J. L. Burch, M. Schulz, and H. Spence, American Geophysical Union, Washington, D. C., 2005.

Frey, H. U., et al., Continuous magnetic reconnection at Earth's magnetopause, *Nature, 426*, 533, 2003a.

Frey, H. U., et al., Proton aurora in the cusp during southward IMF, *J. Geophys. Res., 108(A7)*, 1277, doi:10.1029/2003JA009861, 2003b.

Frey, H. U., et al., Summary of quantitative interpretation of IMAGE far ultraviolet auroral data, *Space Sci. Rev., 109*, 255, 2003c.

Frey, H. U., et al., Sub-Auroral Morning Proton Spots (SAMPS) as a result of plasmapause-ring-current interaction, *J. Geophys. Res., 109*, A10,304, doi: 10.1029/2004JA010516, 2004a.

Frey, H. U., et al., Localized aurora beyond the auroral oval, *Rev. Geophys.*, submitted, 2004b.

Fuselier, S. A., et al., Ion outflow observed by IMAGE: Implications for source regions and heating mechanisms, *Geophys. Res. Lett., 28,* 1163, 2001.

Fuselier, S. A., et al., Cusp aurora dependence on interplanetary magnetic field Bz, *J. Geophys. Res., 107,* 1111, doi:10.1029/2001JA900165, 2002.

Fuselier, S. A., et al., Cusp dynamics and ionospheric outflow, *Space Sci. Rev., 109*, 285, 2003.

Fuselier, S. A., et al., Generation of transient dayside sub-auoroal proton precipitation, *J. Geophys. Res., 109,* A12,227, doi:10.1029/2004JA010393, 2004.

Fuselier, S. A., et al., Computing the reconnection rate at the Earth's magnetopause using two spacecraft observations, *J. Geophys. Res., 110*, A06212, doi: 10.1029/2004JA010805, 2005a.

Fuselier, S. A., et al., Combined in situ and remote sensing of ionospheric ion outflow, *Geophys. Res. Lett.*, submitted, 2005b.

Gallagher, D. L., IMAGE creates new names to describe invisible cloud features, http://image.gsfc.nasa.gov/poetry/discoveries/n47.html, 2002.

Gallagher, D. L., and M. L. Adrian, The origin and evolution of plasmaspheric notches, *J. Geophys. Res., 110*, in press, 2005.

Galvan, D., M. B. Moldwin, and B. R. Sandel, EUV observations of diurnal refilling of the plasmasphere, to be submitted to *J. Geophys. Res.,* 2005.

Goldstein, J., and B. R. Sandel, The global pattern of evolution of plasmaspheric drainage plumes, in *Inner Magnetosphere Interactions: New Perspectives from Imaging*,edited by J. L. Burch, M. Schulz, and H. Spence, American Geophysical Union, Washington, D. C., doi:10.1029/2004BK000104, 2005.

Goldstein, J., et al., IMF-driven overshielding electric field and the origin of the plasmaspheric shoulder of May 24, 2000, *Geophys. Res. Lett., 29(16)*, doi:10.1029/2001GL014534, 2002.

Goldstein, J., B. R. Sandel, P. H. Reiff, and M. R. Hairston, Control of plasmaspheric dynamics by both convection and sub-auroral polarization stream, *Geophys. Res. Lett., 30(24)*, 2243, doi:10.1029/2003GL018390, 2003a.

Goldstein, J., et al., Overshielding event of 28-29 July 2000, *Geophys. Res. Lett., 30(8),* 1421, doi: 10.1029/2002GL016644, 2003b.

Goldstein, J., B. R. Sandel, M. R. Hairston, and S. B. Mende, Plasmapause undulation of 17 April 2002, *Geophys. Res. Lett., 31*, L15,801, doi:10.1029/2004GL019959, 2004a.

Goldstein, J., et al., Simultaneous remote-sensing and in situ observations of plasmaspheric drainage plumes, *J. Geophys. Res., 109,* A03,202, doi:10.1029/2003JA010281, 2004b.

Goldstein, J., et al., Global plasmasphere evolution 22–23 April 2001, *J. Geophys. Res.*, 110, doi: 10.1029/2005JA011282, 2005a.

Goldstein, J., et al., Magnetospheric model of subauroral polarization stream, *J. Geophys. Res., 110*, doi:10.1029/2005JA011135, 2005b.

Goldstein, J., et al., Coupled response of the inner magnetosphere and ionosphere on 17 April 2002, *J. Geophys. Res., 110,* A03,205, doi:10.1029/2004JA010712, 2005c.

Goldstein, J., et al., Dynamic relationship between the outer radiation belt and the plasmapause during March–May 2001, *Geophys. Res. Lett., 32,* L15,104, doi:10.1029/2005GL023431, 2005d.

Grebowsky, J. M., Model study of plasmapause motion, *J. Geophys. Res., 75*, 4329, 1970.

Green, J. L., et al., On the origin of kilometric continuum, *J. Geophys. Res., 107(A7),* doi:10.1029/2001JA000193, 2002.

Green, J. L., et al., Seasonal and solar cycle dynamics of the AKR source region, *J. Geophys. Res., 109,* A05,223, doi:10.1029/2003JA010311, 2004a.

Green, J. L., et al., Association of kilometric continuum radiation with plasmaspheric structures, *J. Geophys. Res., 109*, A03,203, doi:10.1029/2003JA010093, 2004b.

Green, J. L., et al., On the origin of whistler mode radiation in the plasmasphere, *J. Geophys. Res., 110,* A03,201, doi:10.1029/2004JA010495, 2005.

Gurgiolo, C., The image high-resolution data set, *Space Sci. Rev., 91*, 461, 2000.

Huang, T. S., R. A. Wolf, and T. W. Hill, Interchange instability of the Earth's plasmapause, *J. Geophys. Res., 95*, 17,187, 1990.

Huang, X., et al., Developing an empirical density model of the plasmasphere using IMAGE/RPI observations, *Adv. Space Res., 33*, 829, 2004.

Hubert, B., et al., Observation of dayside subauroral proton flashes with the IMAGE-FUV imagers, *Geophys. Res. Lett., 30*, doi:10.1019/2002GL016464, 2003.

Hubert, B., et al., Statistical properties of dayside subauroral proton flashes observed with IMAGE-FUV, in *Inner Magnetosphere Interactions: New Perspectives from Imaging,* edited by M. Schulz, H. Spence, and J. L. Burch, American Geophysical Union, Washington, D. C., 2005.

Immel, T. J., et al., Precipitation of auroral protons in detached arcs, *Geophys. Res. Lett., 29,* doi:10.1029/2001GL013847, 2002.

Immel, T. J., et al., Global observations of the zonal drift speed of equatorial ionospheric plasma bubbles, *Ann. Geophys., 22*, 3099, 2004.

Immel, T. J., et al., Global storm time plasma redistribution imaged from the ground and space, *Geophys. Res. Lett., 32,* L03,107, doi:10.1029/2004GL021120, 2005.

Jaggi, R. K., and R. A. Wolf, Self-consistent calculation of the motion of a sheet of ions in the magnetosphere, *J. Geophys. Res.,* 78, 2852, 1973.

Kennel, C. F., and H. E. Petschek, Limit on stably trapped particle fluxes, *J. Geophys. Res., 71*, 1, 1966.

Korth et al., H., Conditions governing localized high-latitude dayside aurora, *Geophys. Res. Lett., 31,* L04,806, doi:10.1029/2003GL018911, 2004.

Lallemant, R., et al., Deflection of the interstellar neutral hydrogen flow across the heliospheric interface, *Science, 307,* 1447, 2005.

Lemaire, J. F., and K. I. Gringauz, *The Earth's Plasmasphere,* Cambridge University Press, Cambridge, 1998.

Lin, C.-S., et al., Simultaneous observations of equatorial plasma depletions by IMAGE and ROCSAT-1 satellites, *J. Geophys. Res., 110*, A06,304, doi:10.1029/2004JA010774, 2005.
Lyons, L. R., R. M. Thorne, and C. F. Kennel, Pitch-angle diffusion of radiation belt electrons within the plasmasphere, *J. Geophys. Res., 77*, 3455, 1972.
Mende, S. B., et al., FAST and IMAGE-FUV observations of a substorm onset, *J. Geophys. Res., 108(A9),* 1344, doi:10.1029/2001GL013027, 2002.
Mende, S. B., et al., IMAGE and FAST observations of substorm recovery phase aurora, *Geophys. Res. Lett., 29(12),* 1602, doi:10.1029/2002JA009787, 2003.
Mitchell, D. G., et al., Global imaging of O+ from IMAGE/HENA, *Space Sci. Rev., 109*, 63, 2003.
Moldwin, M. B., B. R. Sandel, M. Thomsen, and R. Elphic, Quantifying global plasmaspheric images with in situ observations, *Space Sci. Rev., 109*, 47, 2003.
Moore, T. E., et al., Heliosphere-geosphere interactions using low energy, *Space Sci. Rev., 109*, 63, 2003.
Ober, D. M., et al., Premidnight plasmaspheric plumes, *J. Geophys. Res.*, 102, 11,325, 1997.
O'Brien, T. P., and M. B. Moldwin, Empirical plasmapause models from magnetic indices, *Geophys. Res. Lett., 30(4)*, doi:10.1029/2002GL016007, 2003.
Ostgaard N., et al., Observations of non-conjugate theta aurora, *Geophys. Res. Lett., 30(21)*, 2125, doi:10.1029/2003GL017914, 2003.
Ostgaard, N., et al., Interplanetary magnetic field control of the location of substorm onset and auroral features in the conjugate hemispheres, *J. Geophys. Res., 109,* 10.1029/2003JA010,370, 2004.
Petrinec, S., and S. A. Fuselier, On continuous versus discontinuous neutral lines at the dayside magnetopause for southward interplanetary magnetic field, *Geophys. Res. Lett., 30*, 2125, doi:10.1029/2002GL016565, 2003.
Phan et al., T., Simultaneous cluster and image observations of cusp reconnection and auroral proton spot for northward imf, *Geophys. Res. Lett., 30*, 1509, doi: 10.1029/2003GL016885, 2003.
Pierrard, V., and J. F. Lemaire, Development of shoulders and plumes in the frame of the interchange instability mechanism for plasmapause formation, *Geophys. Res. Lett., 31,* L05,809, doi:10.1029/2003GL018919, 2004.
Pilkerton, B. M., M. R. Collier, and T. E. Moore, Correlations between neutral and ionized solar wind, *Adv. Space Res.*, in press, 2005.
Pollock et al., C., The role and contributions of energetic neutral atom (ENA) imaging in magnetospheric substorm research, *Space Sci. Rev., 109*, 155, 2003.
Pulkkinen, T., et al., *Physics and Modeling of the Inner Magnetosphere,* Geophysical Monograph 155, American Geophysical Union, Washington, DC 2005.
Reinisch, B.W., et al., Plasmaspheric mass loss and refilling as a result of a magnetic storm, *J. Geophys. Res., 109,* A01,202, doi:10.1029/2003JA009948, 2004.
Richards, P. G., and D. G. Torr, Seasonal, diurnal, and solar cyclical variations of the limiting H+ flux in the Earth's topside ionosphere, *J. Geophys. Res., 90*, 5261, 1985.
Roelof, E. C., et al., Derivation of currents and diamagnetic effects from global plasma pressure distributions obtained by IMAGE/HENA, *Adv. Space Res., 33(5)*, 747, 2004.
Sandel, B. R., et al., Initial results from the IMAGE extreme ultraviolet imager, *Geophys. Res. Lett., 28*, 1439, 2001.
Sandel, B. R., J. Goldstein, D. L. Gallagher, and M. Spasojevic, Extreme ultraviolet imager observations of the structure and dynamics of the plasmasphere, *Space Sci. Rev., 109*, 25, 2003.
Scime, E. E., et al., Ion temperature imaging of space plasmas, *IEEE Trans. Plasma Sci.,* in press, 2005.
Singh, N., and J. L. Horwitz, Plasmasphere refilling: Recent observations and modeling, *J. Geophys. Res., 97*, 1049, 1992.
Spasojevic, M., et al., Global response of the plasmasphere to a geomagnetic disturbance, *J. Geophys. Res., 108(A9)*, 1340, doi:10.1029/2003JA009987, 2003a.
Spasojevic, M., et al., Plasmaspheric loss estimates, *EOS Trans AGU*, Abstract SM52E-04, 2003b.
Spasojevic, M., et al., The link between a detached subauroral proton arc and a plasmaspheric plume, *Geophys. Res. Lett., 31,* L04,803, doi:10.1029/2003GL018389, 2004.
Spasojevic, M., J. Goldstein, and B. J. Anderson, Evidence of effective shielding in the inner magnetosphere, *J. Geophys. Res.,* submitted, 2005a.
Spasojevic, M., M. F. Thomsen, P. J. Chi, and B. R. Sandel, Afternoon subauroral proton precipitation resulting from ring current–plasmasphere interaction, in *Inner Magnetosphere Interactions: New Perspectives from Imaging*, edited by M. Schulz, H. Spence, and J. L. Burch, American Geophysical Union, Washington, D. C., 2005b.
Su, Y.-J., M. F. Thomsen, J. E. Borovsky, and J. C. Foster, A linkage between polar patches and plasmaspheric drainage plumes, *Geophys. Res. Lett., 28*, 111, 2001.
Trattner, K. J., et al., Reconnection sites of spatial cusp structures, *J. Geophys. Res., 110*, A04207, doi:10.1029/2004JA010722, 2005a.
Trattner, K. J., et al., The location of the reconnection line for southward IMF, AGU Meeting, May, 2005b.

Tu et al., J.-N., Simulating plasmasphere field-aligned density profiles measured with IMAGE/RPI: Effects of ion heating and refilling, *J. Geophys. Res., 108(A1)*, 1017, doi:10.1029/2002JA009468, 2003.

Vallat, C., I. Dandouras, P. C:son Brandt, and D. G. Mitchell, First comparison between ring current measurements by cluster/CIS and IMAGE/HENA, *J. Geophys. Res., 109,* A04,213, doi:10.1029/2003JA010224, 2004.

Woodger et al., L. A., Investigation of relativistic electron precipitation using groundbased and satellite data during the MINIS balloon campaign, *GEM 2005 Meeting*, 2005.

Wurz P., et al., Possible origin of the secondary stream of neutral fluxes at 1 AU, *AIP Conference Proceedings, 719,* 195, 2004.

Yizengaw E., et al., The correlation between mid-latitude trough and the plasmapause, *Geophys. Res. Lett., 32*, L10,102, doi:10.1029/2004JA010920, 2005.

Zeng, W., Near-simultaneous Polar and DMSP measurements of topside ionospheric field-aligned flows at high latitudes, *J. Geophys. Res., 106*, 29,601, 2001.

Zhang, X. X., et al., Deduction of ion temperature in the ring current from energetic neutral atom (ENA) images, *Geophys. Res. Lett.,* submitted, 2005.

Zhang, Y., et al., Negative ionospheric storms seen by the image fuv instrument, *J. Geophys. Res., 108,* doi:10.1029/2002JA009797, 2003.

Zhang, Y., et al., O/N_2 changes during 14 October 2002 storms: IMAGE SI-13 and TIMED/GUVI observations, *J. Geophys. Res., 109*, doi:10.1029/2004JA010441, 2004.

Education and Public Outreach

The IMAGE Education and Public Outreach component is called POETRY (Public Outreach, Education, Teaching and Reaching Youth) (http://image.gsfc.nasa.gov/poetry). POETRY produces high-quality, innovative educational products that explain space physics concepts to teachers and students in the K-12 community, participates in teacher training, and communicates the latest insights from IMAGE to the general public. POETRY addresses the Education Strategy of NASA: "to accomplish the goal to inspire and motivate students to pursue careers in science, technology, engineering, and mathematics and to strongly support the goal to engage the public in shaping and sharing the experience of exploration and discovery." **Table EPO-1** lists these requirements and demonstrates how IMAGE satisfies them.

A. Accomplishments

IMAGE Educational Products. In 2005, IMAGE/POETRY contributed content on the aurora and space weather to the NASA/LRC "SciFiles" TV program "The Case of the Technical Knockout," which was shot on location in Norway and was seen by an estimated 1 million students nationwide. This was the most recent in a series of educational television programs in which IMAGE/POETRY has been involved. POETRY co-hosted "Dancing in the Night Sky," a program on auroral physics broadcast on April 10, 2003 and seen by over 300,000 teachers and over five million students nationwide. In 2002 IMAGE collaborated with NASA/CONNECT in the program "Having a Solar Blast," which reached seven million students and 330,000 teachers. This video is being used in the Rice University ASTR 202 and 402 courses and in "Sun-Earth Day."

IMAGE/POETRY has completed two new educational products: (1) "Adventures in Space Science Mathematics" and (2) "Extra-Credit Problems in Space Science." We also provided the content for the SECEF (Sun-Earth Connection Education Forum) Student Observation Network's magnetometer program, which used the IMAGE/POETRY Soda Bottle Magnetometer to track geomagnetic storms during the 2003 Sun-Earth Day. Beginning in 2005, we have distributed via email a new educator resource called the "IMAGE Space Science Problem of the Week," which provided a new problem each week for students in grades 7-10. They include many science and engineering problems based on the IMAGE mission. Science problem sets are posted weekly (http://image.gsfc.nasa.gov/poetry/weekly/weekly.html) and are advertised through our 2,800 "e-teacher" national teacher subscriber list. Based on the response from over 200 teachers, this resource is filling an important niche in science and math education, and we are extending our distribution list next year to include homeschoolers.

Through its collaboration with SECEF, IMAGE/POETRY has been able to distribute its education products to over 60,000 teachers at national conventions and NASA-sponsored teacher training workshops. ***IMAGE has produced more educational products, and a wider range of product concepts, than any other S^3C mission during this time.*** IMAGE/POETRY-developed products include the POETRY web site with 50 downloadable classroom activities in space science, a weekly problem set archive, seven major space science workbooks, an award-winning education video "Blackout," contributions to planetarium shows, and the Space Weather CD-ROM, which has been identified as an Exemplary NASA Education Resource (IMAGE/POETRY-developed educational material about the aurora has also appeared

Table EPO-1. IMAGE-POETRY fully meets NASA Education program requirements.

Requirements	IMAGE-POETRY Qualities
Customer focus	POETRY meets educator needs with K-12 curriculum development and teacher workshops, and museum needs for exhibits and shows. Customer surveys and field trials ensure usefulness of materials developed.
NASA content	SEC focus, with explanations of magnetic fields, charged particles, the aurora, and IMAGE discoveries related to these phenomena.
Contribution to the NASA education pipeline	Teacher training in space physics concepts, development of elementary and secondary science curricula, inputs on magnetospheric and auroral science for astronomy textbooks.
Diversity	Teacher training and school workshops have involved numerous ethnic groups including Alaskan native Americans and Hispanic and black communities. Lectures and exhibits at conferences support diverse populations such as SACNAS and AAPT.
Evaluation	POETRY has received numerous awards from NASA, educational organizations, and the media. Received "exemplary" status from formal evaluation panel.
Sustainability	The products developed by POETRY are inserted into the Sun-Earth Connection Education Forum and the National Space Science Data Center. Distribution as part of Space Update CD-ROM allows some revenue to continue distribution of material.

as supplementary material on the DVD release of the motion picture *Frequency*.) Another product is a sample page for undergraduate astronomy texts correctly describing the magnetosphere and the origin of aurora. This page was developed to rectify the misconception, found in most such texts, that the bulk of the auroral emissions are excited by solar wind particles impinging directly on Earth's upper atmosphere. Copies of this page have been sent to the authors of astronomy textbooks. For educators and the general public, POETRY has produced a growing archive on its web site of significant IMAGE "Discoveries." Each Discovery presents a short abstract of a recent IMAGE result, along with an appropriate image that graphically highlights the discovery and gives links to additional resources Discoveries is a valuable, quick introduction to IMAGE's accomplishments since 2000. The impact of POETRY's various products is indicated by a tabulation of their content and the size of the audience reached since IMAGE/POETRY was initiated in 1997 (**Table EPO-2**).

Several POETRY products have had independent evaluations and have won many awards. The "Blackout!" video won Crystal Awards in The Communicator Video Competition in 1999 in the categories of Education and Special Effects/Animation. "Blackout!" also won two Telly Awards. The POETRY web site was selected for the Study Web Academic Excellence Award. The Soda Bottle Magnetometer Activity was selected as a high-quality resource by the National Science Teachers Association (NSTA) as part of their SciLinks program. Many POETRY products have been reviewed and approved for inclusion in the Space Science Education Resource Directory <http://teachspacescience.stsci.edu>, such as the Space Weather CD-ROM and a number of our downloadable workbooks, including "Exploring the Earth's Magnetic Field," "Northern Lights and Solar Sprites," "Solar Storms and You," "Exploring Satellite Design," "Exploring Magnetic Storms," "Exploring the Wind from the Sun," and "Exploring Sunspots and Solar Activity Cycles."

Teacher Professional Development. POETRY supports teachers in developing new curriculum materials each summer. Our teachers, Ms. Sue Higley, Mr. Tom Smith, Mr. Bill Pine, and Ms. Dorian Janney, each have over 10 years of experience in middle school and/or high school science and math instruction. Ms. Higley was chosen Teacher of the Year for Maryland in 2000 and is a nationally-certified master teacher in middle-school mathematics. POETRY has also participated in Rice University's "Masters of Science Teaching" degree program, with six graduates so far and three more teachers in progress. IMAGE content is included in ASTR 202, 402 and PHYS 401 classes.

Media and Public Outreach. In addition to the EPO activities of POETRY, the IMAGE project continues to be a major player in keeping S^3C science in the public eye through media outreach. IMAGE has had eleven press releases since launch, generating over one hundred

Table EPO-2. The content and audience size of IMAGE products since 1997.

Product Type	Title	Teachers	Students	Public	Web Hits
Video	Blackout!	350	42,000	-	-
DVD	**Frequency** supplemental material	-	-	~100,000	-
Web Site	Ask the Space Scientist	-	-	-	21 million
Web Site	POETRY	-	-	-	24.5 million
NASA-TV	NASA/Connect March 15, 2002	320,000	7.3 million	-	-
NASA-TV	NASA/Connect April 10, 2003	300,000	6.3 million	-	-
NASA-TV, PBS	"Live from the Aurora" 2003				
NASA-TV	NASA/CONNECT March 19, 2004	200,000	6 million		
NASA-TV	NASA/CONNECT March 21, 2005	300,000	6 million		
NASA-TV	SciFiles, April 19, 2005	100,000	1 million		
Student Activity	Soda Bottle Magnetometer	-	-	-	110,050
Curriculum	Workbooks	60,840	61,000	-	-
CDROM	"Space Weather"	540,000	750,000	130,000	1.1 million-
Student Help	Science Fair Suggestions	-	-	-	39,000
Multimedia	Data movies	-	-	-	123,500
Lithograph	Space Weather	25,000	-	1000	-
VLF Receiver Kit	INSPIRE Natural Radio Project	1,800	54,000	200	4.5 million
Museum Exhibits	Houston Museum of Natural Science, Lodestar Museum, etc.	15,000	120,000	250,000	.7 million-
Planetarium Shows	"Force 5" "Night of the Titanic"	12,000	60,000	150,000	-
Essay Contest	Alaskan Northern Lights	-	182	-	-
Workshops	Teacher Training	2,000	-	-	-
TOTALS		**18.8 million**	**27.7 million**	**531,000**	**52.1 million**

newspaper articles (http://image.gsfc.nasa.gov/press_release/) and stories in magazines such as *Scientific American, Science News,* and *Physics News*. In 2002, IMAGE was the first geospace mission to hold a Space Science Update (SSU), "Earth's Space Storm Shield Offers Protection at a Price." Since then, IMAGE science has been profiled in two further SSUs:

• "Stormy Space Weather Slips Through the Cracks" (December 3, 2003), presented in conjunction with the publication in *Nature* [*Frey et al.*, 2003] of a joint IMAGE/FUV-Cluster result on high-latitude reconnection

• "IMAGE Discovers Cause of Unusual Van Allen Belt Distortions" (December 15, 2004), a joint SSU/press conference on the discovery, reported in *Nature* [*Baker et al.*, 2004], of the link between plasmaspheric erosion and the shrinkage of the slot region and the associated Earthward movement of the outer radiation belt during a major magnetic storm.

"Force 5," a planetarium show that uses IMAGE data and highlights IMAGE science, is being distributed by Evans & Sutherland, a leading visual simulation technology company, and is now available in portable theaters in six cities. We are also working with the American Museum of Natural History on their next major planetarium show "Cosmic Collisions", which will feature IMAGE data in the part of the show that deals with CMEs.

Figure EPO-1. Fisheye image of students watching the CME portion of "Force 5" which features the IMAGE spacecraft and actual image auroral images and modeled field lines from a geomagnetic storm. (shown in an inflatable full dome portable theater at an elementary school in San Antonio, TX).

B. Future Plans

POETRY in 2005-2006. IMAGE will continue to develop innovative educational products and to partner with other NASA EPO programs, including the SECEF, IDEAS, LWS, and THEMIS programs in order to ensure the widest possible distribution of its products. We will continue to provide Weekly Space Science Problems to our rapidly growing list of teachers and homeschoolers. We will continue to add to the "Discoveries" web pages and will annually revise the "Space Weather" CD, by improving and expanding its content, and manage its reproduction and distribution. We will support one or two teacher interns per year at Rice University and during the summers at GSFC.

A particular focus of POETRY activities during the next two years will be the development of additional Internet resources suitable for the NSTA SciLinks program. SciLinks is a program, supported by a grant from NASA and by fees from textbook publishers, that identifies and evaluates supplementary material for K-12 science textbooks and provides links to it over the World Wide Web. (The supplementary resources are identified by topics and SciLink code numbers in the margins of textbooks.) By participating in this growing program, IMAGE ensures that its valuable insights into aurora and space science will be available to hundreds of thousands of teachers across the country. Currently, POETRY has a single SciLink page at the web site that features our "Soda Bottle Magnetometer," which has been used by thousands of teachers since 1997.

IMAGE/POETRY will participate in the EPO component of the THEMIS mission, a MIDEX mission to study substorms with a constellation of spacecraft (scheduled launch: 2005). As part of the THEMIS investigation, geomagnetic data will be collected at 10 ground-based magnetic observatory stations operated by selected high schools in Illinois, North Dakota, Wisconsin, and Minnesota. POETRY will help develop explanatory documents that show how these data can be used by teachers to support existing course studies of magnetism and the geospace environment. POETRY resources such as the "Soda Bottle Magnetometer" will be used as a springboard to learning about high-precision geomagnetic investigations. Resources developed by POETRY for THEMIS will also connect the THEMIS substorm investigations with real-time IMAGE data for specific substorm events, so that students can understand the coupling between particles-and-field phenomenology from actual case studies.

IMAGE/POETRY is also participating in outreach from the CLUSTER and MMS missions, and will distribute materials developed for those missions.

POETRY developed a new product for SECEF's Sun-Earth Day 2004 that discusses long-term changes in the geomagnetic field (e.g., polar wander, magnetic reversals) the climate and explores the possible consequences of such changes for the magnetosphere and geospace environment. POETRY will also broaden the scope of the IMAGE data to encompass a comparative planetology theme, linking IMAGE results to the exploration of planetary magnetospheres (e.g., ENA imaging of Saturn's inner magnetosphere) and core dynamo activity. An additional POETRY activity during this period will be to support the development of planetarium shows, including "Cosmic Collision" from the Carnegie Museum of Natural History (CMNH), and to create activities which will accompany that show.

POETRY in 2006-2007. We will continue to create full-dome planetarium show segments that can be used in many productions and to revise and distribute the Space Weather CD. We are embarking on adapting a new web-based technology, Podcasting, to further educate the Public about space weather and space science issues; many of which are raised by the new research performed by IMAGE.

Podcasting is an exciting, new technology that will allow us to create radio-style programs, and distribute them through many web services such as iPodder.com. Currently, there is no serious science content being offered to millions of user of this technology. We plan to fill this niche in ca 2006 with regularly-produced, 2-3 minute programs featuring a new discovery or issue in space weather science and forecasting. These programs will also be used in our education activities, and to make our POETRY web offerings '501-compliant' for visitors with visual diabilities.

POETRY in 2008 and Beyond. Although some of what POETRY has accomplished in 1996-2005 was foreseen in the initial IMAGE EPO plan, many significant opportunities arose that were not foreseen. Most notably the partnering with SECEF in 1998, the award-winning NASA/CONNECT TV programs in 2002-2005, the Event-Based Science "Blackout!" product, the NSTA SciLinks program in 2001, and the central role that POETRY played in suggesting the Venus Transit 2004 SECEF theme. Podcasting, for example, was not invented until 2004. We fully expect that the years 2007 and beyond will present IMAGE/POETRY with further "unexpected" opportunities to contribute in innovative ways to the education and public outreach goals of the Office of Space Science.

Meanwhile, 2008 and beyond will include the onset of the next sunspot cycle, and the deployment of new generations of space weather satellites whose education programs are now being designed. Our collaborations with Themis, MMS, Solar-B and SECEF will guarantee that IMAGE science and education products continue to be used for the foreseeable future.

Our evolving role in space science education has been to create high-quality math and science activities for teachers and students, rather than the customary posters, bookmarks, and other memorabilia. This approach has paid off in that IMAGE/POETRY is routinely consulted by other NASA missions for insight to creating hands-on math and science classroom products.

We are also involved in systemic education reform at the Parkland Magnet School of Aerospace Technology in Rockville, Maryland. We plan to invest more heavily in these higher-order activities in the coming years, so that we can help change the climate for space science education in our schools, thereby making our existing classroom resources more "main stream."

Our involvement with textbook writing, which began with Holt, Rinehart and Winston in 2003, will continue as new editions of middle school and high school textbooks are developed. IMAGE/POETRY has been instrumental in literally "re-writing the textbooks" on how space science is presented, and corrected misconceptions about auroral physics.

ACRONYMS

ACE – Advanced Composition Explorer
AKR – Auroral Kilometric Radiation
ASI – All Sky Imager
AST – Autonomous Star Tracker
BBF – Bursty Bulk Flow
CDAWeb – Coordinated Data Analysis Web
CDF – Common Data Format
CHAMP – Challenging Minisatellite Payload
CIDP – Central Instrument Data Processor
CIR – Corotating Interaction Region
C/NOFS – The Communication/Navigation Outage Forecasting System
CME – Coronal-Mass Ejection
COSMIC - Constellation Observing System for Meteorology, Ionosphere and Climate
CPU – Central Processing Unit
CRL – Communication Research Laboratory
DGCPM - Dynamic Global Core Plasma Model
DMSP – Defense Meteorological Satellite Program
DSN – Deep Space Network
EMIC – Electromagnetic Ion Cyclotron
ENA – Energetic Neutral Atoms
E/PO – Education and Public Outreach
EPS – Electrical Power System
EUV – Extreme Ultraviolet Imager
FAC – Field-Aligned Current
FAST – Fast Auroral Snapshot Explorer
FTE – Flux Transfer Event
FTP – File Transfer Protocol
FITS – Flexible Image Transfer System
FOV – Field of View
FUV – Far Ultraviolet Imager
GEO – Geocoronal Imager
GPS – Global Positioning System
GRACE – Gravity Recovery and Climate Experiment
GSRI – Geospace System Response Imager
GUVI – Global Ultraviolet Imager
HENA – High-Energy Neutral Atom Imager
HiLDA - High Latitude Dayside Aurora
HVPS – High-Voltage Power Supply
IBEX – Interstellar Boundary Explorer
IDEAS - The Initiative to Develop Education through Astronomy and Space Science
IDL – Interactive Data Language
IMAGE – Imager for Magnetopause-to-Aurora Global Exploration
IMF – Interplanetary Magnetic Field
ISNA – Interstellar Neutral Atom
ISS – IMAGE Software Suite
IT – Ionosphere-Thermosphere
LANL – Los Alamos National Laboratory
LENA – Low-Energy Neutral Atom Imager
LMMS – Lockheed Martin Missiles and Space Co.
LWS – Living with a Star
MCP – Microchannel Plate
MENA – Medium-Energy Neutral Atom Imager
MHD - Magnetohydrodynamics
MIME – MENA Image Making Engine
M-I – Magnetosphere-Ionosphere
M-I-T – Magnetosphere-Ionosphere-Thermosphere
MLT – Magnetic Local Time
MMM – Mass Memory Module
MOU – Memorandum Of Understanding
MSM – Magnetospheric Specification Model
NSSDC – National Space Science Data Center
NSTA – National Science Teachers Association
NTC – Non-Thermal Continuum
OSS – Office of Space Science
PEACE - Plasma Electron And Current Experiment on Cluster
POETRY – Public Outreach Education, Teaching and Reaching Youth
RBSP – Radiation Belt Storm Probes
RCM – Rice Convection Model
RHESSI - Reuven Ramaty High Energy Solar Spectroscopic Imager
ROCSAT – Republic of China Satellite
RPI – Radio Plasma Imager
S^3C – Sun - Solar System Connections
SAMPEX – Solar Anomalous and Magnetospheric Particle Explorer
SAMPS – Sub-Auroral Morning Proton Aurora Spots
SCU – System Control Unit
SEC – Space Environment Center
SECEF – Sun-Earth Connection Education Forum
SI – Spectrographic Imager
SI-12 – Proton Auroral Imager
SI-13 – Electron Auroral Imager
SMOC – Science and Mission Operations Center
SOC – State Of Charge
SOHO – Solar and Heliospheric Observatory
SPASE – Space Physics Archive Search and Extract
Sq – Solar Quiet Day
SSU – Space Science Update
STEREO – Solar-Terrestrial Relations Observatory
SWAN – Solar Wind Anisotropies Instrument on SOHO
TAS – Time-Attitude Synchronization Software
TEC – Total Electron Content
THEMIS – Time History of Events and Macroscale Interactions during Substorms
TIMED – Thermosphere Ionosphere Mesosphere Energetics Dynamics
TWINS – Two Wide-angle Imaging Neutral Spectrometers
UCB – University of California, Berkeley
UDF – Universal Data Format
URL – Uniform Resource Locator
VMO – Virtual Magnetospheric Observatory
VO – Virtual Observatory
V_xO – Virtual Observatories
WHISPER - Whisper of High Frequency and Sounder for Probing Electron Density by Relaxation
WIC – Wide-band Imaging Camera