THE INNER MAGNETOSPHERIC IMAGER (IMI):
INSTRUMENT HERITAGE AND ORBIT VIEWING ANALYSIS

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Introduction

For the last two years an engineering team in the Program Development office at MSFC has been doing design studies for the proposed Inner Magnetospheric Imager (IMI) mission. This team had a need for more information about the instruments that this mission would carry so that they could get a better handle on instrument volume, mass, power, and telemetry needs as well as information to help asses the possible cost of such instruments and what technology development they would need. To get this information an extensive literature search was conducted as well as interviews with several members of the IMI science working group. The results of this heritage survey are summarized below.

There was also a need to evaluate the orbits proposed for this mission from the stand point of their suitability for viewing the various magnetospheric features that are planned for this mission. This was accomplished by first, identifying the factors which need to be considered in selecting an orbit, second, translating these considerations into specific criteria, and third, evaluating the proposed orbits against these criteria. The specifics of these criteria and the results of the orbit analysis are contained in the last section of this report.

Heritage Summaries for the IMI Instruments

FUV Auroral Imagers

Of all of the proposed IMI instruments the FUV auroral imager has the greatest amount of heritage. Instruments designed to image the aurora have been flown for over 20 years. They have been designed to operate from low altitude (500–1000 km) and high altitude (6000 km–3.5 Re), and to image the aurora at wavelengths from the vacuum ultraviolet through the near infrared. These instruments have flown at low altitude on a series of air force weather service satellites (DMSP) during the late sixties and seventies and on their air force descendents (HILAT and Polar Bear) during the eighties. A series of Japanese satellites (Exos A–Exos D) also carried FUV auroral tv cameras. The instruments with the closest applicable heritage to IMI are the V5 auroral imager flown on the Swedish Viking satellite in 1986 (*Anger et al.*, 1987), the Scanning Auroral Imager (SAI) launched on Dynamics Explorer 1 in 1981 (*Frank et al.*, 1981), and the Ultraviolet Imager (UVI) scheduled for launch on the ISTP POLAR spacecraft in June of 1983 (*Torr et al.*, 1992). Of these last three UVI comes closest to meeting the IMI requirements; its main drawback is that its field of view (8° full cone) is too small to meet the IMI requirement of 30° × 30°.

Geocoronal Imagers

In the last 20 years two instruments have been flown which had the capability to image the hydrogen geocorona. The first, in 1972, was a electronographic Schmidt f/1 system operated from the moon's surface by the Apollo 16 astronauts. The second was the SAI instrument carried on DE 1. In addition to its ability to image the aurora SAI also had the capacity to image the geocorona. Of these two instruments the SAI instrument is the closest to meeting the IMI requirements. In fact, a simplified version of SAI would probably be adequate to the task.

He$^+$ 304 Å Imager

This instrument has no direct heritage; no He$^+$ 304 Å imagers have flown in the past. The signal that it would measure (solar 304 Å light scattered by plasmaspheric He$^+$ ions) has been detected by photometer and spectrometer instruments flown in the past so we know that there is a signal to measure and what its intensity is. We also know from these previous measurements that this signal contains information on the structure of the plasmasphere. The question then is: Can an imaging instrument be built to take pictures of the plasmasphere given the intensity of the 304 Å scattered sunlight coming from it? A compact telescope (ALEXIS) designed to do an all sky survey in several soft x-ray bands (133 Å, 171 Å, 186 Å) has many of the features needed for a He$^+$ imager (*Bloch et al.*, 1990). To modify ALEXIS so that it could operate at 304 Å would require a redesigned multilayer mirror and transmission filter. Such modifications have been made and a He$^+$ imager called WIDGET will fly this fall (Sept. 1992) to test the instrument (*Cotton et al.*, 1992).

O$^+$ 834 Å Imager

Like the 304 Å imager, this instrument has no direct heritage. Furthermore, it is not clear that the 834 Å emission levels from O$^+$ ions in the magnetosphere are large enough to be detected, especially since

these emissions would often need to be seen against the dayside ionosphere which is a strong producer of 834 Å emissions. The filtering system for this instrument would also need sufficient out of band rejection to eliminate the strong Lyman-α signal coming from the geocorona. A conceptual design for a self-filtering 834 Å camera, which has in theory sufficient out of band rejection, was recently proposed by *Zukic et al.* (1991), but has not yet been tested. Some limited work has been done on fabricating and testing filters for this instrument, but the work is still in its early stages. Before IMI could fly a O$^+$ imager a great deal of work needs to be done to demonstrate that a working 834 Å imager can be built and that a strong enough signal exists to be detected above the background.

Electron Precipitation Imager

Spacecraft instruments detected bremsstrahlung x-rays coming from the auroral ionosphere, in regions of energetic electron precipitation, as early as 1972. Since then a series of satellites have carried x-ray detectors whose data have furthered our knowledge about these emissions and permitted a limited amount of imaging, all from low altitude. For IMI, an x-ray auroral imager capable of simultaneously imaging the whole auroral oval from altitudes as high as 7 Re, has been proposed. No previous instrument with capabilities even close to these has been flown. An x-ray imager to be carried on the ISTP POLAR spacecraft (called PIXIE–Polar Ionosphere X-ray Imaging Experiment) (*Imhof et al.*, 1991) will attempt to do many of the things that are expected of the IMI electron precipitation imager. Several though, have expressed there doubts about how well it will work and if the x-ray fluxes will be high enough for it to make useful measurements from the higher altitude portions of the POLAR orbit. Even if PIXIE works perfectly it will still fall short of meeting the IMI requirements of angular resolution and energy detection range for this instrument. Much work needs to been done to demonstrate an x-ray imaging instrument capable of meeting the IMI requirements.

Proton Aurora Imager

The first detection of doppler shifted Lyman-α coming from precipitating protons (charge exchanged into precipitating hydrogen atoms) was made by a spectrometer flown on the S3-4 satellite in 1978 (*Ishimoto et al.*, 1989). No instrument however, has ever imaged these emissions so the proton auroral imager has no direct heritage. Such an instrument would need to spectrally separate Lyman-α emissions coming from the proton aurora and Lyman-α emissions coming from the geocorona. To do so would require good spectral resolution near 1216 Å (≤ 1 Å), which also gives the instrument the capability to determine the energy distribution of the precipitating protons as well. An instrument designed to do high spatial and spectral resolution (0.04 Å) imaging of Jupiter, in order to study proton aurora there, was flown on a sounding rocket in 1991 (*Harris et al.*, 1992). The imaging portion of this instrument was a telescope with a small field of view, appropriate for imaging a distant target. To adapt it to the task of imaging terrestrial proton aurora at close range would require a front end telescope with a wider field of view and good angular resolution.

Neutral Atom Imagers

The use of neutral atoms for imaging the magnetosphere involves a concept totally different from that used by the instruments discussed above. Here the medium of information are streams of neutral atoms originating from energetic ring current ions which have charge exchanged with hydrogen in the geocorona. The instrument must focus this stream onto an imaging surface capable of detecting it. The only direct heritage for this instrument was a charge particle detector (MEPI) which flew on the ISEE-1 spacecraft. It was only realized some time after the initial measurements were made that the persistent fluxes seen when the spacecraft was outside the region containing the energetic ions were really neutral atoms that the detector was able to see. From this data a crude image of the ring current was made (*Roelof*, 1987). Since then much work has been done defining ENA camera concepts and testing the various components and processes needed for such a camera (*McEntire and Mitchell*, 1989). Much work remains to be done testing full engineering models to see if the techniques needed to reject ions, electrons and photons will work. An instrument with neutral atom imaging capability (SEPS) will be carried on the POLAR despun platform, and a dedicated ENA imager (ISENA) will fly on the SAC-B satellite in 1994.

In addition to an instrument capable of imaging energetic neutral atoms (20–100 keV) as discussed above, IMI will carry a Low Energy Neutral Atom imager (LENA) for the ~ 1–50 keV energy range.

This instrument is still in the early conceptual stage and a detailed candidate instrument design has yet to proposed (*McComas et al.*, 1992). Work is currently underway to test the interaction of LENA with thin foils and crystalline surfaces. These processes may play important roles in the operation of any LENA camera.

Magnetospheric Viewing Considerations for IMI

Since the primary aim of the IMI mission will be to obtain global images of the inner magnetosphere and the aurora, viewing considerations should play a major role in the orbit selection process. By viewing considerations we refer to those factors which determine whether or not the particular magnetospheric feature can be seen from the spacecraft, what kind of quantitative information can be obtained from the given viewing location, what fluxes will be available at the viewing location, when other sources will interfere with viewing, etc. Listed here, in order of priority, are the image target regions along with the wavelengths or means of imaging. The means of imaging following each target are listed in order of feasibility and/or importance.

1. Auroral zone (1304 Å, 1356 Å, LBH; Lyman-α; x-rays)
2. Ring current and ion injection region (ENA; LENA; O^+–834 Å)
3. Plasmasphere (He^+–304 Å; O^+–834 Å)
4. Atomic hydrogen geocorona (Lyman-α)
5. Inner plasma sheet (LENA; O^+–834 Å)
6. Polar cap low energy ions ($\leq$ 40 eV) (O^+–834 Å; He^+–304 Å)
7. Ionosphere (O^+–834 Å)

Targets 1–3 are absolutely necessary to the success of the mission and are all of about equal importance. Target 4 is also important, at least for analysis of ENA images. Targets 5 and 6 are important from the perspective of understanding the magnetosphere but are of lower priority because of technical difficulties associated with their imaging. Target 7 is of low importance to the magnetospheric investigation role of the mission, but is something which could be easily seen if an 834 Å camera flies on IMI.

Because of the high priority for imaging the auroral zone, the ring current and the plasmasphere considerations affecting their imaging are also of high priority. These considerations are:

1. An unobstructed view of the whole auroral oval.
2. Dwell times at high altitude and latitude that are comparable to auroral evolution time scales.
3. Keeping the sun out of the field of view of those instruments which could see it (FUV, electron aurora imager, proton aurora imager).
4. Whether magnetic local time versus radial distance, or latitude versus radial distance information is desired for the ring current and plasmasphere.
5. The easy of understanding a ring current and plasmasphere images when viewed from outside versus the inside.
6. Higher ENA and 304 Å fluxes (by a factor of at least 2) are available when the ring current and plasmasphere are viewed from outside rather then inside.
7. Orbital period compared to ring current and plasmasphere evolution time scales.

Because of the easy of imaging the geocorona, no specific viewing considerations other than an orbit with an apogee above 3 Re are needed. The plasma sheet, polar cap low energy ions, and the ionosphere require a viewing location at high altitude and low altitude. Because of the lower priority of these features this consideration was not added to the list used to analyze the following orbits.

These viewing considerations were translated into the following specific criteria by which the candidate orbits (see table) were evaluated.

1. The length of time per orbit when the spacecraft is within the auroral oval viewing region.
2. The length of time per orbit when the angle between the spacecraft–sun line and the spacecraft–earth line is less than 20° and the spacecraft altitude is less than 2 Re. (These are times when auroral imaging would not be possible.)
3. The length of time per orbit that the spacecraft is within the plasmasphere and ring current.
4. The length of time per orbit that the spacecraft is within the three latitude bins of 0°–30°, 30°–60°, and 60°–90°.

Candidate Orbits

Orbit	Perigee	Apogee	i	ω_a	d_a	Launch Date	Period(hrs)
#1	4844 km	7 Re	90°	290°	0°	20 Sept.	15.179
#2	4844	7	90°	335°	0°	20 Sept.	15.179
#3	1000	7	90°	270°	0°	20 Sept.	13.795

Each of these orbits have periods long enough to follow auroral substorms, plasmasphere depletions, and ring current injection events. They do not however, offer long enough continuous coverage to follow plasmasphere refilling and ring current decay. Orbit #1 provides the best auroral viewing over the two years of the mission, while orbit #3 allows the viewing of the ring current and plasmasphere from a variety of latitudes. The amount of time spent inside the plasmasphere and ring current is about the same for each orbit so that this criteria does little to discriminate between these orbits. Non of these orbits have times when criteria 2 is met.

It turns out that the requirement for good auroral viewing is in conflict with low latitude viewing. Therefore, if it is decided that having a variety of latitudes from which to view the plasmasphere and ring current is less important than having good auroral viewing, orbit #1 would be most desirable. In this case it would be possible to chose an initial orbit so that during a extended mission, beyond two years, low latitude coverage is provided. If it is decided that latitude coverage is as important as auroral viewing then orbit #2 might be an option. Viewing of several of the secondary targets (polar cap ions, inner plasma sheet, and ionosphere) all require long dwell times at low latitudes, which taken together might tip the balance in favor of an orbit like #3 which spends significant time at low latitudes. Of the three orbits, orbit #1 provides the most time over the life of the mission where the full auroral oval, ring current and plasmasphere can be imaged simultaneously.

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