THE INTERSTELLAR BOUNDARY EXPLORER (IBEX) MISSION

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ABSTRACT

The Interstellar Boundary Explorer (IBEX) is scheduled to launch in June 2008 to make the first global observations of the heliosphere's interaction with the interstellar medium. IBEX achieves these breakthrough observations by traveling outside of the Earth's magnetosphere in a highly elliptical, high-apogee orbit and taking global Energetic Neutral Atoms (ENA) images over energies from ~10 eV to 6 keV. IBEX's orbit enables heliospheric ENA measurements by providing viewing from outside the earth's relatively bright magnetospheric ENA emissions, and is achieved by adding an IBEX-supplied solid rocket motor on top of a standard Pegasus launch vehicle. IBEX carries two very large-aperture, single-pixel ENA cameras that view perpendicular to the spacecraft's sun-pointed spin axis. Over the course of each six months, the spacecraft spin and progression of the sun-pointing spin axis in inertial space naturally lead to global, all-sky images. McComas et al. (2004) described the IBEX science background, requirements, and measurement strategies; here we summarize IBEX's measurement approach and mission. Additional information on IBEX is also available at www.ibex.swri.edu.

1. IBEX SCIENCE

The sole focused science objective of IBEX is to discover the global interaction between the solar wind and the interstellar medium. The interstellar interaction encompasses the structures, dynamics, energetic particle acceleration and charged particle propagation in the complex region where the solar wind interacts with the interstellar medium. IBEX will provide the first global observations of this interstellar interaction – disclosing its fundamental nature and providing the observations needed for detailed modeling and in-depth understanding. IBEX achieves this objective by collecting and using all-sky ENA images and energy spectra to answer four fundamental science questions:

Question I: What is the global strength and structure of the termination shock?
Question II: How are energetic protons accelerated at the termination shock?

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Question III: What are the global properties of the solar wind flow beyond the termination shock and in the heliotail?
Question IV: How does the interstellar flow interact with the heliosphere beyond the heliopause?

The background image in Fig. 1 summarizes the basic interaction expected at the edge of the heliosphere. This interaction leads to three distinct interstellar boundaries: 1) innermost, the termination shock (TS) where the solar wind slows from supersonic to subsonic; 2) the heliopause (HP), which separates the solar wind from the local interstellar medium (LISM); and 3) furthest out, a bow shock (BS) or bow wave beyond which the local interstellar flow is unperturbed by the heliosphere. The recent IGPP symposium on the Physics of the Outer Heliosphere documented our present understanding of the physics of these regions (edited by Florinski, Pogorelov and Zank, 2004).

The cartoon in the lower right corner of Fig. 1 represents charge exchange, which converts some heliospheric ions into ENAs. In the outer heliosphere, hydrogen ENAs are produced from multiple populations, including solar wind, pickup and energetic protons. Heliospheric ENAs are generated predominantly beyond the TS, in the inner heliosheath, where the previously supersonic solar wind is abruptly slowed and heated. In this region of slower, hotter solar wind, a significant flux of ENAs is produced from protons that charge-exchange with interstellar neutrals. Some of the ENAs propagate back into 1 AU where they can be imaged by IBEX.

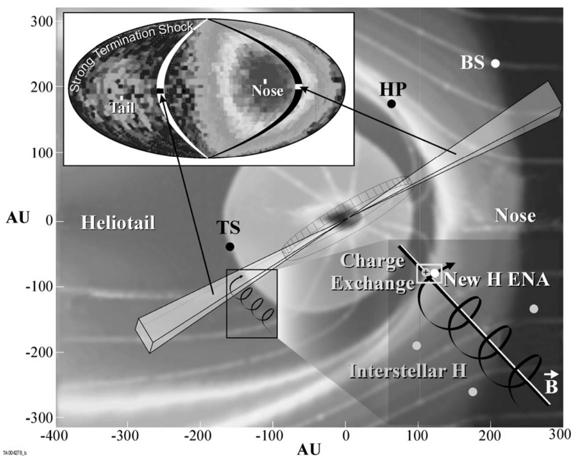

Figure 1. Conceptual diagrams of heliospheric interaction with two example viewing pixels (background) and cartoon of charge exchange process (lower right inset). The upper left inset shows a simulation by Gruntman et al. (2001) of 300-600 eV ENAs, with added Poisson noise, for a strong termination shock case. The view directions between the crescent-shaped lines are swept out each spin.

The two pixels (light shading) show IBEX's instantaneous viewing, and the arrows indicate how these view directions are mapped into an all-sky image (upper left inset). IBEX samples all of the pixels in the two crescent-shaped swaths in the upper left inset over each 15s spacecraft spin. Repointing of the spacecraft once each orbit keeps the solar cells facing the Sun and moves the crescents viewed across the sky. Except for the directions where IBEX is viewing through the magnetosphere, this combination provides for essentially all-sky viewing each six months that IBEX is on orbit. In addition, evolution of the orbit over its two-year mission allows IBEX to fill in directions initially obscured by the magnetosphere.

2. IBEX MISSION DESIGN

The IBEX technical approach is based on three building blocks: 1) a very simple science payload employing flight-proven sensor technologies to provide very high sensitivity and low background ENA observations; 2) an innovative mission design that allows a very small, lightweight spacecraft to be launched into a highly elliptical orbit from a standard Pegasus XL launch vehicle; and 3) the use of extremely low-risk, high-heritage designs, subsystems, software, and facilities.

The IBEX mission design maximizes science viewing time outside of and looking away from the comparatively bright magnetospheric ENA emissions. This is achieved by placing IBEX into a high-altitude (25-50 R_E apogee) orbit. During our Phase A study we carried out a comprehensive set of systems-engineering trade studies to optimize the approach to achieving this orbit with minimal risk. Our solution uses a standard Pegasus launch vehicle with IBEX providing a STAR 27 Solid Rocket Motor (SRM) and adapter hardware. IBEX will launch from an L-1011 aircraft flying out of Kwajalein Atoll in the south pacific. At 11° latitude, this approach provides the largest mass-to-orbit performance from any existing Pegasus launch site. Once it achieves a 200-km injection orbit, the Pegasus third stage will point IBEX in the proper orientation for the SRM burn and spin it up using its cold gas Reaction Control System. This operation was modeled during Phase A using the Pegasus high-fidelity 6 Degrees Of Freedom (6DOF) flight-simulation tool, which verifies flight operations for all Pegasus missions. IBEX then ejects the Pegasus upper stage and ignites the SRM. Roughly 11 minutes after Pegasus ignition, IBEX will be in orbit, traveling toward its high-altitude apogee. A few days later near its first apogee, we use the IBEX hydrazine propulsion system to raise perigee to ~7000 km, placing IBEX into a permanent, low-radiation dose orbit. IBEX's Sun-pointing solar array is always illuminated (including during SRM burn and all thruster firings) so it remains in a naturally power-safe state with stable thermal characteristics and ample time to identify, diagnose, and rectify any issues.

The ~5 day orbital period allows for extremely simple mission operations. With the exception of the ground-tested, pre-planned check-out and contingency modes, and a few eclipse orbits per year, each orbit's operations are essentially identical. Science observations are taken when IBEX is above 10 R_E and stored in memory. Below 10 R_E, the science payload is put in low-power standby mode, and IBEX executes a small (~ 5°) spin-axis reorientation maneuver that fixes the spin-axis pointing for the entire following orbit. The spacecraft then performs a single, short (<1 hour) telemetry pass where it downlinks that orbit's mission data, receives an upload of a few pre-calculated timing commands, and provides ground tracking for orbital determination. If needed for any emergency, IBEX has adequate telemetry link for communications at all altitudes throughout its orbit.

3. IBEX SPACECRAFT & PAYLOAD

The IBEX spacecraft is built from Orbital's off-the-shelf, high-reliability MicroStar subsystems and supporting software. These systems and software have been proven on 38 successful MicroStar spacecraft and include some functional redundancy and proven autonomous fault detection and correction capabilities. Fig. 2 shows the basic layout of the IBEX spacecraft. The top, sun-pointing surface is covered with solar cells, while the IBEX-Hi and -Lo sensors look off orthogonal to the spin axis with 7° FWHM conical fields of view. In order to minimize mass, IBEX features a simple, thrust-tube-based structure with substantial strength and stiffness margins. The IBEX hydrazine propulsion system features a fully flight-qualified architecture with significant excess capacity. Because IBEX is a simple spinning spacecraft, thermal design and pointing margins are robust and easily achieved.

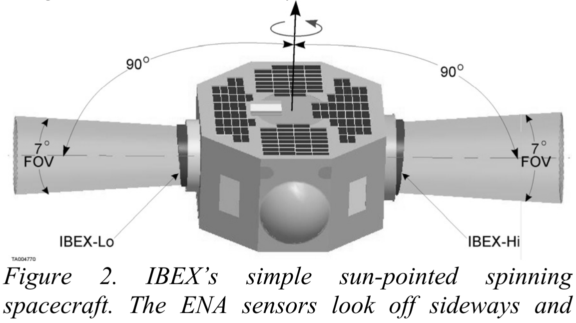

Figure 2. IBEX's simple sun-pointed spinning spacecraft. The ENA sensors look off sideways and sweep out swaths of the sky each spacecraft spin.

As one of the team's approaches to minimizing risk, we deliberately chose not to use any new technologies. The mission's top technical challenges are ensuring successful SRM operations, dealing with the complications of a minor-axis spinner while the SRM is still attached, and maintaining robust mass margins. Successful SRM operations are ensured by careful attention to detail in the design and verification of the SRM elements, including the test firing of an identical qualification SRM. In addition, we have carefully considered the lessons learned from previous missions, including CONTOUR, and addressed them in our design and program plans.

The IBEX payload is extremely simple with only two large, single-pixel ENA sensors (IBEX-Hi and IBEX-Lo) and a single Combined Electronics Unit (CEU) that controls the sensors, stores data, and is the payload interface to the spacecraft bus (Fig. 2).

Both sensors are based on the same four subsystems, as shown schematically in Fig, 3. ENAs enter the sensors through multi-plate collimators, based on the SEPICA collimators from ACE (Möbius et al., 1998), but with the addition of biasing some of the plates to also reject charged particles. ENAs within the 7 deg FWHM passband either strike an ultra-smooth diamond surface, producing reflected negative ions (IBEX-Lo), or pass through an ultra-thin carbon foil (McComas et al., 2004) producing positive ions (IBEX-Hi). Below the charge conversion sections are electrostatic analyzers, which bend and select the negative (Lo) and positive (Hi) ions and reject stray photons. Finally, the time-of-flight mass spectrometer (Lo) and coincidence detector (Hi) backends provide precise measurements of the particles transmitted through the sensors with very high signal-to-noise rejection.

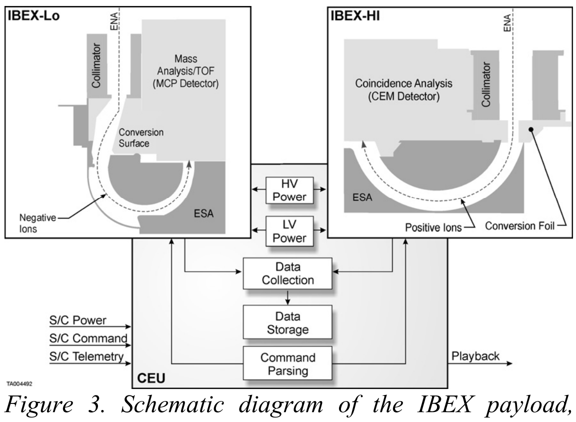

Figure 3. Schematic diagram of the IBEX payload, which consists of two large-aperture sensors, IBEX-Lo (~10eV-2keV) and IBEX-Hi (~300eV-6keV), and a Combined Electronics Unit.

Both IBEX sensors were prototyped during Phase A, and the test results validated the designs and expected sensitivities and resolutions. The sensors are straightforward extensions of previous flight-proven instruments and incorporate heritage subsystems to minimize development risk. Overlap in measurements between IBEX-Lo (~10 eV to 2 keV) and -Hi (~300 eV to 6 keV) 1) maximizes statistics, 2) allows for in-flight cross-calibration, and 3) provides imaging via two completely independent means across the most critical energy range for achieving the IBEX science objective.

4. GROUND SEGMENT AND E/PO

The IBEX approach to mission operations builds on Orbital's Mission Control Center, which has been used to control over 30 spacecraft, and on SwRI's extensive experience in managing science operations and data analysis. IBEX uses the Tracking and Data Relay Satellite System (TDRSS) for real-time data during the SRM burn and the existing Universal Space Network (USN) ground stations once it is on orbit.

The SwRI IBEX Science Operations Center (ISOC) is responsible for evaluating mission data, monitoring payload performance, and delivering IBEX data products. It plans the operations and generates the detailed science and engineering schedule. The ISOC processes all mission science and calibration data and provides timely validation, dissemination and archiving of IBEX data, ensuring that the science community has rapid access to IBEX science products. In addition to funding for the IBEX science team, we have set aside $2M for an IBEX-funded, NASA-peer-reviewed and selected guest-investigator program to support outside researchers. This guest-investigator program specifically targets the coordinated use of IBEX data products to iteratively refine 3D heliospheric models. IBEX guest investigators will participate as full members of the science team.

In addition to providing groundbreaking observations for the discovery, exploration, and deep understanding of the heliosphere's interstellar interaction, IBEX also provides valuable information for other areas of space science. Because IBEX culls out magnetospheric ENAs from our heliospheric ENA observations, IBEX produces very high-sensitivity magnetospheric observations, which are provided to that community for scientific analysis. In addition, astrophysical-heliospheric, cross-disciplinary research is also enabled by IBEX as we explore synergies in understanding between our heliosphere and astrospheres throughout the galaxy.

Finally, IBEX is already beginning to carry out a very comprehensive Education and Public Outreach (E/PO) program, which is overseen and implemented by Adler Planetarium and Astronomy Museum. Our program develops exciting themes from both Solar/Space Physics and Astronomy and incorporates a nationally distributed planetarium show with accompanying informal education materials that are accessible to individuals with special needs, a national Space Science Core Curriculum for grades 6-8 in collaboration with other NASA missions, a professional development program for teachers, and workshops that engage Hispanic & Native American students. Additional information about the IBEX mission and our E/PO program are available at www.ibex.swri.edu .

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