INTERSTELLAR BOUNDARY EXPLORER (IBEX)
PROJECT LEVEL REQUIREMENTS

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SwRI® Project 11343

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Contract NNG05EC85C

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REVISION NOTICE

Initial Issue:	Draft 1	Submitted to NASA for review
Second Issue:	Rev 0, Chg 0	Section 4.1.5 remove “happen to” Section 4.3 Change reference section to 4.1 Section 4.5 Add NASA Space debris requirements Update signature page Add acronym list Submit to NASA as deliverable
Third Issue:	Rev 0, Chg 1	Sec 4.1.3: Added "at least" Sec 4.1.4: Changed "determine" to "centroid" and "2° to 0.2°" Sec 4.5: Change Kwaj to "IBEX specified" Sec 4.6: Remove Orbital and SwRI from MCC and ISOC requirements. Change to “The IBEX team shall” Sec 7: Correct heading to be "Education and Public Outreach" Submitted to NASA with above changes
Fourth Issue:	Rev 0, Chg 2	Sec 4.1.4: Changed "centroid" to "determine" and "0.2° to 2.0°"

1. SCOPE

This document, which is appended to the Explorer Program Plan, identifies the mission, science, and programmatic (funding and schedule) requirements imposed on Southwest Research Institute (SwRI) and the NASA/Goddard Space Flight Center (GSFC) for the development and operation of the IBEX Mission of the Small Explorer Program. Requirements begin in Section 4.0. Sections 1, 2 and 3 are intended to set the context for requirements, which follow.

This document serves as the basis for mission assessments conducted by NASA Headquarters during the development period and provides the baseline for the determination of the science mission success during the operational phase.

Program authority is delegated from the Associate Administrator for the Science Mission Directorate (AA/SMD) through the GSFC Center Director to the Explorer Program Manager within the Flight Projects Directorate at GSFC. The Principal Investigator (PI) at SwRI is responsible for the overall success of the IBEX Mission and is accountable to the AA/SMD for the scientific success and to the GSFC Center Director for the programmatic success. The GSFC Program Management Council (PMC) is the governing PMC for the IBEX Mission. The GSFC Center Director is responsible for certifying IBEX flight readiness to the Associate Administrator for Space Science.

The PI at SwRI is responsible for design, development, test, mission operations, and coordinating the work of the contractors and co-investigators. For the scientific investigation and the data verification tasks, the PI will use the set of approved co-investigators reflected in the proposal, amended by any approved changes prior to the release of this document.

Changes to information and requirements contained in this document require approval by the IBEX PI, the Associate Administrator, Science Mission Directorate (AA/SMD) and NASA Headquarters. This document will be reviewed periodically and updated as needed. In case of a dispute that cannot be resolved among the signatories, higher-level management from each organization will meet to resolve the difference.

2. SCIENCE DEFINITION

2.1 Baseline Science Objectives

The primary science objective for the IBEX mission is to discover the global interaction of the solar wind and the local interstellar medium. IBEX will address this objective through global neutral atom imaging of the heliosphere from a high-altitude Earth orbit. By taking global images of charge exchange neutral atoms that arise from the solar wind, pickup ions and energetic protons beyond the termination shock over the energy range ~0.01-6 keV IBEX will enable the three dimensional (3D) visualization of the heliosphere and the resolution of the strength and structure of the termination shock for the first time.

Specific scientific questions to be addressed by IBEX are as follows. What is the global strength and structure of the termination shock? How are energetic protons accelerated at the termination shock? What are the global properties of the solar wind flow beyond the termination shock and in the heliotail? How does the interstellar flow interact with the heliosphere beyond the heliopause?

The science return is considered on three levels. At the first level, IBEX data products directly provide ***discovery*** of fundamental properties of the interstellar interaction. At the second level, a combination of IBEX data products and simple physics-based calculations, theory and limited modeling provide ***exploration*** of global fundamental properties of the interstellar interaction. At the third level, IBEX data

products used to define and refine 3D models of the heliosphere provide detailed ***understanding*** of in-depth global properties of the interstellar interaction.

2.2 Summary Description of Science Mission

The IBEX mission payload consists of two single-pixel energetic neutral analyzer (ENA) sensors (IBEX-Hi and -Lo) and a Combined Electronics Unit (CEU), which commands and stores data from the sensors and is the payload interface to the spacecraft bus. Both sensors are straightforward extensions of previous instruments and incorporate heritage subsystems to reduce development risk. IBEX-Lo is optimized to measure 0.01-2 keV oxygen and hydrogen, and IBEX-Hi is optimized to measure 0.3-6 keV hydrogen. Both sensors have 7° x 7° FWHM fields of view. The sensors use biased and grounded collimator plates to set the angular resolution and block charged particles. Incoming neutrals are ionized either negatively (at the conversion surface of IBEX-Lo) or positively (at the foil of IBEX-Hi). The energy of the ionized neutrals is measured using toroidal (bundt-pan type) electrostatic analyzers. Carbon foils are used to produce secondary electrons for Time of Flight (TOF) information in IBEX-Hi and coincidence measurements in IBEX-Lo.

The IBEX spacecraft is a simple Sun-pointing spinner with a bus built from Orbital Sciences Corporation's MicroStar subsystems. The spacecraft is coupled with an adapter cone and modified ATK STAR 27 solid rocket motor (SRM) to form the IBEX flight system. Launch is performed on a standard Pegasus XL and, after SRM burn and initial perigee raise, which is performed using the spacecraft's onboard thrusters, IBEX is in a nominal 37 Earth Radii x 7000 km orbit. Supporting software is designed to operate the spacecraft autonomously and safely over the course of each orbit (~5 days), between ground contacts.

3. PROJECT DEFINITION

3.1 Project Organization Management

The Principal Investigator, Dr. David J. McComas, at SwRI, leads a development team consisting of SwRI, Los Alamos National Laboratory, Orbital Sciences Corporation, Lockheed Martin Advanced Technology Center, the University of New Hampshire, Johns Hopkins University Applied Physics Laboratory, the University of Bern, and NASA Goddard Space Flight Center. IBEX Education and Public Outreach is led by the Adler Planetarium and Science Museum.

Science support and data analysis will be provided by the above institutions and the Polish Academy of Sciences, the University of Bonn, the Ruhr-Universitaet Bochum, the University of Chicago, the University of Southern California, Moscow State University, University of California at Riverside, University of Maryland and NASA Ames Research Center.

3.2 Project Acquisition Strategy

SwRI provides the project management and systems engineering, IBEX-Hi detector development, CEU, payload level integration and test, integrated payload calibrations, payload and science operations, and data processing and archiving. GSFC provides Mission management and support and IBEX-Lo conversion development. The Orbital Sciences Corporation provides the spacecraft, solid rocket motor and Mission Control Center (MCC). Lockheed Martin ATC provides IBEX-Lo systems engineering and sensor development. Los Alamos National Laboratory provides IBEX-Hi systems engineering, sensor development and calibration. The University of Bern provides calculations, models and calibration of the IBEX-Lo sensor. The University of New Hampshire provides development of collimators and the IBEX-

Lo TOF subsystem. Adler Planetarium provides education and public outreach. Johns Hopkins University APL provides IBEX-Lo TOF electronics development.

4. PROGRAMMATIC REQUIREMENTS

4.1 Baseline Science Requirements

The IBEX mission provides global neutral atom imaging of the outer heliosphere. Through energy and angle resolved images, IBEX addresses the global interaction between the solar wind and the interstellar medium. The baseline requirements of the IBEX mission are as follows.

4.1.1

IBEX shall obtain global (at least 95% of 4π sr.) ENA images unobscured by the magnetosphere over a period of two years.

4.1.2

IBEX shall acquire images of ENAs from near the termination shock with an angular resolution no coarser than 7° x 7° FWHM.

4.1.3

IBEX shall measure the energy spectrum of heliospheric hydrogen at energies from 0.01-6 keV in 14 energy bands, at least 3 of which overlap between IBEX-Hi and -Lo.

4.1.4

IBEX shall measure incoming oxygen atoms from the interstellar medium and centroid their direction of arrival to within 0.2° FWHM.

4.1.5

IBEX shall identify and cull pixels that view the magnetosphere.
IBEX shall accumulate magnetospheric data in a separate data set.

4.2 Minimum Science Requirements

4.2.1

IBEX shall obtain global (at least 50% of 4π sr.) ENA imaging unobscured by the magnetosphere over a period of six months.

4.2.2

IBEX shall acquire images of ENAs from near the termination shock with an angular resolution no coarser than 21° x 21° FWHM.

4.2.3

IBEX shall measure the energy spectrum of heliospheric hydrogen at energies from 0.5-4 keV in at least 4 energy bands.

4.3 Payload Requirements

The IBEX payload shall provide observations as described in Section 4.1.

4.4 Mission and Spacecraft Performance Requirements

The IBEX mission shall be designed for a lifetime of at least two years of on-orbit operation, but nothing in the design shall preclude the mission from lasting four years.

The IBEX mission shall have an initial orbit apogee altitude of 25-50 Earth radii (Re).

Initial orbit apogee shall be < 120° from interstellar upwind direction.

4.5 Launch Requirements

The IBEX spacecraft shall be launched on a Pegasus XL from an IBEX identified location.

NASA shall provide this launch vehicle as well as all launch services through Kennedy Space Center (KSC).

The IBEX team shall follow Launch Site Requirements as described in the Launch Vehicle ICD, Missile System Payload Safety Plan, and NASA Space Debris requirements document.

4.6 Ground System Requirements

The IBEX team shall provide the IBEX Mission Control Center (MCC) to opertate the S/C.

The IBEX team shall provide the IBEX Science Operations Center (ISOC).

4.7 Mission Data Requirements

4.7.1 Science Data Management

The IBEX PI shall be responsible for the initial analysis of the data, delivery to an appropriate data repository, publication of scientific findings, and communication of the results to the public. Additionally, the IBEX PI shall be responsible for collecting engineering and ancillary data necessary to validate and calibrate the scientific data prior to depositing it in a NASA approved data repository. The time required to complete this process shall be the minimum necessary to provide accurate scientific data. The IBEX science database shall be made available to the science community without restrictions or proprietary data rights of any kind.

4.7.2 Data Management Plan

The IBEX mission shall develop a project data management plan to address the total activity associated with the flow of science data, including planning, acquisition, processing, data product generation and validation, archiving, and preservation. The plan shall identify science and supplementary data products, systems associated with handling the data, and the roles, responsibilities, and operational interfaces affecting those data and systems. The project data management plan shall be delivered no later than the IBEX Critical Design Review.

5. NASA MISSION COST REQUIREMENTS

5.1 Cost Cap

The cost of the IBEX mission for studies, design, development, mission operations and data analysis (Phase B through Phase E) is capped at a value to be determined at the IBEX Mission Confirmation Review. The launch vehicle (Pegasus, SELVS KSC, Equatorial) and associated launch services will be provided by the NASA Launch Vehicle Office and managed in accordance with NPD 8610.23, Technical Oversight of Expendable Launch Vehicle (ELV) Launch Services. The cost of these services is included in the Project cost estimate based on the guidelines in the AO.

5.2 Cost Management and Scope Reduction

Provided that Program Level Requirements are preserved, and that due consideration has been given to the use of budgeted contingency and planned schedule contingency, the IBEX Mission shall pursue scope reduction and risk management as a means to control cost.

The IBEX Descope Plan shall include potential scope reductions to the minimum science requirements (PLR 4.2) and the time frame in which they could be implemented. If other methods of cost containment are not practical, the reductions identified in the Descope Plan may be exercised without further NASA approval; however, reduction in scientific capability shall be implemented only after consultation with the Program Scientist. Any potential scope reductions affecting the Minimum Science Requirements (PLR 4.2) shall be agreed to by the signers of the Project Level Requirements Document.

6. EXTERNAL AGREEMENTS

The University of Bern has provided SwRI a Letter of Endorsement for use of their facilities and support services during the duration of the IBEX mission.

7. EDUCATION AND PUBLIC OUTREACH

The IBEX mission shall develop and execute an Education and Public Outreach (E/PO) Plan that is funded at 2% of the originally proposed non-launch vehicle total mission budget.

8. SPECIAL INDEPENDENT EVALUATION

IBEX shall follow all NASA oversight, reporting, and reviews per the IBEX Statement of Work, Integrated Independent Review (IIR) Plan, and Surveillance Plan.

9. ACRONYM LIST

AA/SMD - Associate Administrator for the Science Mission Directorate

ATK – Alliant Techsystems Incorporated

CEU – Combined Electronics Unit

ELV – Expendable Launch Vehicle

ENA – Energetic Neutral Analyzer

E/PO – Education and Public Outreach

FWHM – Full-Width, Half-Maximum

GSFC - Goddard Space Flight Center

IBEX – Interstellar Boundary Explorer

IIR – Integrated Independent Review

ISOC – IBEX Science Operations Center

KSC – Kennedy Space Center

MCC – Mission Control Center

PI – Principal Investigator

PMC - Program Management Council

Re – Earth Radii

SMD – Science Mission Directorate

SRM – Solid Rocket Motor

SwRI – Southwest Research Institute

TOF - Time of Flight