Notes for IBEX Electronic Resource for Informal Educators

Revised Spring 2011

Explanation of this Material

This PDF contains all of the text included in the "Notes" section of each of the PowerPoint slides for the Spring 2011 version of the IBEX background PowerPoint. If you cannot utilize the PowerPoint and wish to use this material, it is recommended that you have this PDF and the background material PDF open side by side so you can read or listen to the slide text and then read or listen to this text.

This material is designed as background material for informal educators who wish to learn more about the IBEX mission, science, and science results. This resource is not suitable for showing to a general public audience in its current configuration.

Several of the slides in the original PowerPoint contain movie clips. Movie clips are associated with slides 6, 12, 22, 30, 38, and 44. Because movies are not embedded in this PDF, descriptions of the content of each of the movies are included in these slides.

Notes for Slide 3

The boundary of Lake Michigan is easy to see, but can you find the boundaries of Chicago's neighborhoods in this image? It is quite difficult! There are no obvious markers that can be used from a distance to identify them.

Notes for Slide 4

The Sun, planets, and Pluto are scaled correctly for size, but this image is not scaled correctly for distance, nor does it include all of the objects in our Solar System.

Notes for Slide 5

In the image used on slide 5, the Sun is in the center (size not to scale). The Earth cannot be seen in this scale. The rings around the Sun refer to the orbits of the outer planets. The tilted ring is the orbit of Pluto.

Much more explanation about the heliosphere and other relevant terms (including those in the image on the original slide) can be found on Slides 8 to 27.

Notes for Slide 6

There are no additional notes for this slide.

Notes for Slide 7

Particles from the Sun (the **solar wind)** stream outward and carve out a protective bubble (the **heliosphere**) in the material between the stars (the **interstellar medium** (ISM)). The edge of this bubble is called the **heliopause**; the **heliopause** is the boundary of our Solar System, past which no more solar wind material can flow. The interactions between the solar wind particles and ISM particles create **energetic neutral atoms** (ENAs), which are particles with no charge that move very quickly. IBEX collects some of the ENAs which happen to stream inward toward Earth. The mass, direction of travel, and energy of these particles provide information about the Solar System's boundary.

Notes for Slide 8

There are no additional notes for this slide.

Notes for Slide 9

There are no additional notes for this slide.

Notes for Slide 10

There are no additional notes for this slide.

Notes for Slide 11

In a solid, the atoms are tightly bound together. Solids have a fixed volume and shape. Heating up a solid will often cause it to change to a liquid. Liquids have atoms that are less tightly bonded together. They have a fixed volume, but not a fixed shape. Adding heat energy to a liquid will often transform it to a gas. Gasses have neither a fixed volume nor a fixed shape. Their atoms are not bonded together and they move around freely. When heat energy is added to a gas, the particles forming the gas begin to move around faster.

Notes for Slide 12

In a solid, the atoms are tightly bound together. Solids have a fixed volume and shape. Heating up a solid will often cause it to change to a liquid. Liquids have atoms that are less tightly bonded together. They have a fixed volume, but not a fixed shape. Adding heat energy to a liquid will often transform it to a gas. Gasses have neither a fixed volume nor a fixed shape. Their atoms are not bonded together and they move around freely. When heat energy is added to a gas, the particles forming the gas begin to move around faster. When enough heat energy is added to a gas, electrons separate from their atoms, forming a **plasma**. Plasma can react to magnetic fields.

Plasma is similar to gas, but its particles have a different structure and charge. Plasma forms when a gas becomes extremely hot. When this happens, the gas' atoms gain lots of energy. This energy causes the electrons to detach from the nuclei of the gas' atoms. When the negatively charged electrons detach, the positively charged protons and neutral particles called neutrons in the nuclei are left. These positively charged nuclei are called ions. When a gas is so hot that the electrons detach from their nuclei to form a "soup" of electrons and ions, we say that the gas has been ionized. Plasma is composed of ions and electrons.

Plasma has some interesting properties because the particles are ionized. When charged particles move, as they do in a plasma, they create **magnetic fields**. These magnetic fields can then cause the moving plasma particles to travel in certain directions and paths. The particles travel in spiraling paths like corkscrews.

Notes for Slide 13

A flame is the visible portion of fire and consists of glowing hot gases. If hot enough, the gases may become ionized to produce plasma.

When the electric field becomes strong enough either within clouds or between clouds and the ground, an electrical discharge (the bolt of lightning) occurs. During the strike, air is heated to plasma temperatures. It becomes a conductive discharge channel as the electrons and positive ions of air molecules are pulled away from each other and forced to flow in opposite directions.

The material that makes up our Sun is a hot plasma.

Notes for Slide 14

There are no additional notes for this slide.

Notes for Slide 15

Plasma has some interesting properties because the particles are ionized. When charged particles move, as they do in a plasma, they create **magnetic fields**. These magnetic fields can then cause the moving plasma particles to travel in certain directions and paths. The particles travel in spiraling paths shaped like corkscrews.

Notes for Slide 16

The Sun is made of positively charged ions and negatively charged electrons in a state of matter called plasma. Since the Sun is made of charged particles, magnetic fields are created by the movement of the particles.

The Sun's charged particles move in three ways due to the Sun's high temperatures and the rotation of the Sun around its axis, which influence each other to make the Sun's magnetic field complex:

First, the Sun's high temperatures cause the positively charged ions and negatively charged electrons that make up its plasma to move around a lot. The moving plasma creates many complicated magnetic fields that twist and turn. Second, the extremely hot plasma that blows off the Sun as the **solar wind** also creates a magnetic field. Third, the plasma in the Sun rotates around the Sun's axis. The plasma near the poles rotates slower than the plasma at the equator causing twisting and stretching of magnetic fields, too.

The image on this slide shows a model of the Sun’s magnetic field superimposed on an image of the corona, as seen at the time the magnetic field model was created.

Notes for Slide 17

The **solar wind** is a stream of charged particles (plasma) that flow off the Sun at about one million miles per hour (about 1.6 million kilometers per hour). These particles come from the outermost layer of the Sun, called the corona. The corona is a very hot place, about 1.8 million °F (1 million °C). High temperatures cause particles to move faster, so the particles in the corona move very fast. Some of the particles move so fast that the Sun's gravity is not strong enough to hold them down, and so they fly off, becoming part of the solar wind.

By the time that the solar wind reaches the Earth, the particles are still moving at this very fast speed. That is about 1,000 times faster than most supersonic airplanes (these jets fly at about 1,000 miles per hour; or about 1,600 kilometers per hour)! The number of charged solar wind particles and how fast they are moving fluctuates as the activity level of the Sun changes during its 11-year cycle. When the solar wind is particularly strong, it can disrupt satellites and electrical grids on Earth. A very strong solar wind can also cause auroras, also known as the Northern or Southern Lights.

Notes for Slide 18

Outer space is not empty space. The **interstellar medium** (or ISM) is the name for the material that is in space between stars in our Milky Way Galaxy. The ISM is mostly made of clouds of hydrogen and helium. The rest of the ISM mostly consists of heavier elements like carbon. About one percent of the ISM is in the form of dust, usually silicates. In some places in space the ISM is not dense at all, but it is much more dense in other regions. However, even the densest parts of the ISM are 100 trillion times less dense than the Earth's atmosphere. The density of the ISM ranges from 0.003 molecules per cubic centimeter in regions of hot ionized gases, or plasma, to more than 100,000 molecules per cubic centimeter in regions where stars form. On average, there are only 1,000 grains of dust in each cubic kilometer of space! To compare, there are, on average, about 25 quintillion (or 25 followed by 18 zeroes) molecules of air at sea level in the Earth's atmosphere. We'd have a very hard time breathing if our air was only as dense as even the the densest parts of the ISM.

Stars form in regions of the ISM that are dense enough for gravity to pull the gas and dust together to make compact, hot spheres. These protostars eventually become so dense and hot that nuclear fusion begins, and they become stars. Although they are not alive, stars have life-cycles. They are born from the ISM, grow, and die. Stars that are more massive than our Sun die in an explosion called a **supernova**. After it explodes, the former star's material is recycled into the ISM. Exploding stars continually replenish the ISM with their material. In turn, gravity pulls the ISM material together to form more stars.

Notes for Slide 19

The notes for this slide are the same as for Slide 18.

Notes for Slide 20

As the solar wind streams away from the Sun it races out toward the space between the stars containing the interstellar medium. The solar wind blows against this material and clears out a bubble-like region in this gas. This bubble that surrounds the Sun and the Solar System is called the **heliosphere**.

Even though the interstellar medium has a low density, it still has a pressure (similar to air pressure). The solar wind also has a pressure. Close to the Sun, the solar wind has a large pressure and can easily push the interstellar medium away from the Sun. Further away from the Sun, the inward pressure from the interstellar medium is strong enough to slow down and eventually stop the flow of solar wind from traveling into its surroundings. The entire area or bubble inside the termination shock is called the **heliosphere**. This is not a bubble like a soap bubble, but more like a cloud of foggy breath that you breathe into chilly winter air. Scientists believe that the edge of the heliosphere, the **termination shock**, is about 80 times farther away than the distance between the Earth and Sun. That's about two times farther than Pluto is from the Sun. The distance to the **heliopause,** the boundary of our Solar System, is probably about 130 times the distance between the Earth and the Sun (or more), or over three times the distance between the Sun and Pluto.

Notes for Slide 21

The **termination shock** is the boundary layer where the bubble of solar wind particles slows down so that the particles are traveling slower than the speed of sound. The solar wind particles slow down when they begin to press into the interstellar medium. The solar wind is made of plasma, and when it slows in this way, it goes through many changes. The solar wind plasma is compressed, like people crowded together in a tiny room. When it is compressed, it also becomes much hotter, in the same way as a bicycle pump tube heats up in your hand when you vigorously push the air through the tube to inflate a tire. Also, the solar wind carries outward some of the Sun's magnetic field, which now gets stronger at the termination shock and twists around. We have only two direct measurements of the distance to the termination shock. These measurements were made by Voyager 1 and Voyager 2. Voyager 1 reached the termination shock on December 16, 2004 at a distance of 8.4 billion miles (14.1 billion kilometers) from the Sun. Voyager 2 reached the termination shock on August 30, 2007 at a distance of 7.8 billion miles (12.6 billion kilometers) from the Sun. The discrepancy in distances and dates can be explained by the fact that Voyager 1 is traveling faster than Voyager 2, and that the termination shock is not at a uniform distance from the Sun.

The **heliopause** is the boundary between the Sun's solar wind and the interstellar medium. The solar wind blows a "bubble" known as the heliosphere into the interstellar medium. The outer border of this "bubble" is where the solar wind's strength is no longer great enough to push back the interstellar medium. This is known as the **heliopause**, and is often considered to be the outer border of the Solar System.

The zone between the termination shock and the heliopause is known as the **heliosheath**.

Notes for Slide 22

You can create a simple 2-dimensional demonstration of the termination shock when you run water from a faucet into a sink. When the stream of water hits the sink basin, the flowing water spreads out at a relatively fast speed, forming a disk of shallow water that quickly moves outward, like the solar wind inside the termination shock. Around the edge of the disk, a shock front or wall of water forms. Outside the shock front, the water moves relatively slower, as it does outside the termination shock. Remember, the water shock is only 2-dimensional or flat. The boundary of our Solar System is 3-dimensional, like a sphere.

Notes for Slide 23

If you wish to think of the heliosphere in terms of a 3-D model, you can use the analogy of a hard-boiled egg. The yolk represents the solar wind blown outward from our Sun. The boundary between the yellow yolk and the egg white is the termination shock. The white of the egg represents the heliosheath and its more-slowly moving particles. The shell of the egg represents the heliopause.

Notes for Slide 24

A bow shock or bow wave will form in front of the heliosphere, as the Sun moves through the interstellar medium. A bow wave is similar to the water buildup at the front of a moving boat, while a bow shock is similar to the shockwave that forms in front of a jet flying faster than the speed of sound. Whether our Solar System has a bow shock or a bow wave depends on how fast the Solar System is traveling and the density of the material through which it is traveling. We do not know if a bow shock or bow wave exists because we do not know the current conditions in the interstellar medium. The data from IBEX will help scientists determine which configuration actually exists.

On the trailing portion of our heliosphere, the part in the opposite direction to our Sun's motion through the galaxy, probably has a tail that may extend way beyond any of our renditions. But because the two Voyager spacecraft headed outward towards the direction of travel of our Solar System through the galaxy, known as the **nose**, we do not have a lot of information about conditions in the tail or even how long it is. It is hoped that data from IBEX will help answer outstanding questions like this one.

Notes for Slide 25

Information about this image is available in the News Archives at the Hubble Space Telescope website: http://hubblesite.org.

One light-year is the distance light travels in one year, or about 6.6 trillion miles (about 10 million kilometers). A half light-year is the distance light travels in half a year, or about 3.3 trillion miles (about 5 million kilometers).

Notes for Slide 26

Information about this image is available on the WISE mission website: http://www.nasa.gov/mission_pages/WISE/multimedia/gallery/pia13455.html.

Notes for Slide 27

Information about this image is available at the GALEX spacecraft website: http://www.galex.caltech.edu/.

Notes for Slide 28

There are no additional notes for this slide.

Notes for Slide 29

All of the planets in our Solar System are within the heliosphere. In the late 1970s and 1980s, the Voyager spacecraft expanded our knowledge of the outer Solar System. Voyagers 1 and 2 both explored the planets Jupiter and Saturn, and Voyager 2 explored Uranus and Neptune. After their planetary observations, both spacecraft continued outward in different directions. The Voyagers were only supposed to last a few years, but they have continued to operate for over 30 years, well past their designed lifetimes. Today, both Voyagers are taking measurements in the boundary region. IBEX orbits Earth and collects particles coming from the boundary of our Solar System. The data from the Voyagers is combined with IBEX's data, allowing scientists to create a more complete model of the boundary of our Solar System.

Voyager 1 launched September 5, 1977. It is traveling at a speed of about 38,000 miles per hour (60,800 kilometers per hour). Voyager 2 launched August 20, 1977. It is traveling at a speed of about 35,000 miles per hour (56,000 kilometers per hour). At the speeds listed above, you would travel about 10 miles (16 kilometers) in just one second.

To date, the Voyagers have traveled more than twice the distance to Pluto.

Voyager 1 reached the termination shock on December 16, 2004 at a distance of 8.4 billion miles (14.1 billion kilometers) from the Sun. Voyager 2 reached the termination shock on August 30, 2007 at a distance of 7.8 billion miles (12.6 billion kilometers) from the Sun. The discrepancy in distances and dates can be explained by the fact that Voyager 1 is traveling faster than Voyager 2, and that the termination shock is not at a uniform distance from the Sun. This distance can vary with the activity level of the Sun.

More information about the "squashed" termination shock is available at:
http://www.nasa.gov/mission_pages/voyager/termination_shock.html.

Notes for Slide 30

This note is about the movie clip used on this slide. The oval represents the entire sky. Because our spherical sky is represented as a flat map, the shape appears as an oval. V1 and V2 refer to the positions of the Voyager spacecraft (Voyagers 1 and 2) as they travel outward through our Solar System. “Nose” refers to the direction our Solar System is traveling through the Milky Way galaxy. For reference, if you held up this oval and pointed your nose in the same direction as “Nose” on the map, the edges of the oval to the right and left would wrap around you to meet in the middle behind your head. As such, Nose would be the direction of travel of our Solar System, and the edges of the oval would be the direction opposite to the direction of travel of our Solar System (sometimes called the “tail”). As the movie clip plays, the colored map that appears is one of the heliosphere images released by the IBEX team in October 2009. The label above the oval refers to the IBEX-Hi sensor and the energy level of the map. This information is explained much more fully starting on Slide 48.

IBEX's focused science objective is to discover the global interaction between the solar wind and the interstellar medium. IBEX achieves this objective by taking a set of global energetic neutral atom (ENA) images that answer four fundamental science questions:

1) What is the global strength and structure of the termination shock?
2) How are energetic protons accelerated at the termination shock?
3) What are the global properties of the solar wind flow beyond the termination shock and in the heliotail?
4) How does the interstellar flow interact with the heliosphere beyond the heliopause?

Notes for Slide 31

IBEX collects particles within its sensors, but IBEX will never get “filled up”, so to speak. These particles are extremely tiny and there are not a huge number of them that enter the sensors.

Notes for Slide 32

In this graph, the term "1 AU" equals 1 astronomical unit, which is the average distance between the Sun and the Earth, or 93 million miles. The graph on this slide is based on theoretical models of cosmic ray interactions with various parts of our heliosphere. The label "1.00" at the bow shock refers to the total number of cosmic rays that are thought to enter that vicinity (1.00 = 100%). At the inner Solar System, the curved black line indicates that only about 0.20 (or about 20 percent) of the cosmic rays that entered the bow shock would actually make it to Earth. The theoretical numbers of cosmic rays blocked by the heliopause, heliosheath, and termination shock can also be seen on the graph.

Mapping the current state of the heliosphere boundary, called the **heliopause**, will help scientists to determine what this important protective boundary is like. The heliosheath is a layer that protects our Solar System from incoming cosmic rays. Cosmic rays are energetic particles that are often made when a star explodes; other cosmic rays come from the Sun or from as far away as other galaxies. If cosmic rays impact something, they can do damage to atoms and molecules. If the Solar System did not have this boundary, then there would be around 4 times more high-energy cosmic rays that would enter our Solar System.

Life on Earth benefits from two other layers that protect us from cosmic rays – our planet's magnetic field, or **magnetosphere**, and atmosphere. If there were a dramatic increase in the number of cosmic rays entering the Solar System, such as from a nearby supernova, more cosmic rays might then reach the Earth's surface. Damage to the Earth's ozone layer could occur, and cosmic rays could cause damage and mutation to DNA. Additionally, when humankind travels to the Moon again or to other locations in our Solar System, astronauts would be outside of the Earth's atmosphere and magnetosphere, so knowing more about the protective abilities of the heliopause will help us plan for future long-term space travel that is safer for humans.

Notes for Slide 33

There are no additional notes for this slide.

Notes for Slide 34

Satellites launched from a location close to the equator in an eastward direction benefit from the added “kick” that the rotation of the Earth provides, which is around an extra 1,000 miles per hour. This results in a fuel savings for the spacecraft launched from Kwajalein.

Notes for Slide 35

An L-1011 airplane took the Pegasus rocket and the attached IBEX spacecraft to a high altitude. At the right altitude, the Pegasus rocket was dropped from underneath the airplane. A few seconds later, the Pegasus fired its own rockets to propel it and IBEX into space. The satellite had its own small rocket engine that allowed it to climb into a highly elliptical orbit that took it 5/6 of the distance to the orbit of the Moon, or around 200,000 miles (325,000 km) away, at its farthest point, and about 10,000 miles (16,000 km), at its closest point. Even though the farthest point of this orbit was high, it was still very far from the boundary of the Solar System. The distance to the near edge of the heliosphere is around 9 billion miles (14 billion km) from the Earth, or about 90 times the distance between the Earth and the Sun.

IBEX performed an Orbit Maintenance Maneuver in June 2011. Information about this orbital alteration is available on Slide 39.

It is important to realize that IBEX does not travel to the Solar System boundary. It is an Earth-orbiting satellite. It detects particles coming from the boundary to our region of the Solar System.

Notes for Slide 36

There are no additional notes for this slide.

Notes for Slide 37

There are no additional notes for this slide.

Notes for Slide 38

To see actual video of the October 19, 2008 Pegasus rocket launch for IBEX, a video clip and transcript of the audio are available here: http://www.nasa.gov/multimedia/podcasting/ibexlaunch_101908.html.

Notes for Slide 39

IBEX completes an orbital lobe in 9.1 days, and it completes one entire three-lobed orbit every 27.3 days. This is the first time this particular orbit has been used by a NASA spacecraft. Periodically during each orbit, the spacecraft uses antennae that are attached to the outside of the spacecraft to send radio signals to receivers on Earth. Due to the rotation of the Earth each day and IBEX's movement through space, the IBEX team needs a global network of receivers so that, no matter how the satellite and Earth are lined up, there is a receiver available to accept the signal. IBEX is never far from Earth, so it takes a second or less for signals to travel between IBEX and Earth.

IBEX communications are slow, but they do not need to be on par with DSL connections on Earth. Communication from the satellite to the ground is 320,000 bits of information per second, and from the ground to the satellite is only 2,000 bits per second. Compare this to a typical home cable modem connection, where the download speed is often 6 million bits per second, and the upload speed is about 500,000 bits per second! IBEX does not need a high-speed connection, though, since it does not need to transmit a vast amount of information to Earth, just information on the particles it collects. Once on Earth, the signal is sent to the IBEX Mission Control Center in Dulles, Virginia.

Notes for Slide 40

IBEX uses two sensors to collect Energetic Neutral Atoms (ENAs) made from solar wind particles. Solar wind particles are usually charged, meaning they have lost electrons. Another name for a particle that has lost one or more electrons is an “ion”. Sometimes these solar wind ions interact with neutral atoms that come from the Interstellar medium (ISM). Neutral atoms contain equal numbers of protons and electrons. The solar wind ions take electrons from these neutral ISM atoms and get deflected from their original path. Since the solar wind particles are now neutral, they no longer react to magnetic fields in the area. They travel very quickly in a straight line from the spot where the interaction occurred. Some of the ENAs happen to get knocked in a straight line in just the right way so that they travel in through the Solar System toward the IBEX spacecraft. This is how the scientists can map the boundary – they know the direction of travel of the particles since they did not change direction in their travels between the heliopause and the IBEX spacecraft.

IBEX cannot detect the distance that the particles have traveled, only their directions of origin, the time they entered the sensor, their masses, and energy levels. This is enough information, though, to create a map of the boundary that is very useful to scientists.

Notes for Slide 41

There are no additional notes for this slide.

Notes for Slide 42

In the configuration represented by the cutaway graphic, energetic neutral atoms enter the sensor from the top. Please note that while this drawing suggests that the entry system is only on one side of the detector, the entire detector is actually a circular doughnut shape. The entry system, called the “collimator”, blocks unwanted charged particles and stray light while selecting only Energetic Neutral Atoms for analysis. The entrance system also ensures that only particles that enter straight into the detector are analyzed so that an accurate determination of their direction of origin can be ascertained. These neutral particles are then turned into negative ions when they encounter the “ENA to Ion Conversion” material. As they are now ions, the path of each particle can be deflected into the rest of the detector. The “Electrostatic Analyzer” at the bottom of these cutaway graphics, reminiscent of the shape of the bottom of a Bundt cake pan, creates a magnetic field that forces the particles into a curved path. In IBEX-Lo, they then pass into the “TOF (Time of Flight) Instrumentation” in the middle of the sensor, where the velocity of the particles can be determined. The velocity of the particles indicates the energy of the particles. The ribs or fins inside IBEX-Lo also deflect and absorb stray visible and ultraviolet light. Over the course of one day, IBEX-Hi detects, on average, about 480 particles; during that same amount of time, IBEX-Lo detects, on average, about 60 to 100 particles. There are variations in the sensitivity of both detectors, and variations in the number of ENAs emitted by different parts of the sky. For example, at the 1 kilo-electron volt, or 1 keV, energy level, one portion of the sky known as the “IBEX Ribbon” has shown a particle count rate that is three times higher than that detected over the rest of the sky. Information about the IBEX Ribbon can be found on slides 47 to 58.

IBEX-Lo can detect particles with energies ranging from 10 eV to 2,000 eV (0.01 keV to 2 keV) in 8 energy bands. The minimum energy level for Energy Level 1, also called Energy Step 1, is 0.01 keV. The maximum energy level for Energy Step 1 is 0.19 keV. The minimum energy level for Energy Step 2 is 0.019 keV. The maximum energy level for Energy Step 2 is 0.038 keV. The minimum energy level for Energy Step 3 is 0.038 keV. The maximum energy level for Energy Step 3 is 0.073 keV. The minimum energy level for Energy Step 4 is 0.073 keV. The maximum energy level for Energy Step 4 is 0.141 keV. The minimum energy level for Energy Step 5 is 0.141 keV. The maximum energy level for Energy Step 5 is 0.274 keV. The minimum energy level for Energy Step 6 is 0.322 keV. The maximum energy level for Energy Step 6 is 0.58 keV. The minimum energy level for Energy Step 7 is 0.66 keV. The maximum energy level for Energy Step 7 is 1.158 keV. The minimum energy level for Energy Step 8 is 0.66 1.418. The maximum energy level for Energy Step 8 is 2.388 keV.

For comparison:
Visible light photons have electron volt energies of 1.5 to 3.5 eV.
13.6 eV is the energy required to ionize one atom of hydrogen.
High energy diagnostic medical X-ray photons have energies of around 200,000 eV (0.2 MeV).
1 TeV (1 trillion electron volts) is the energy of motion of a flying mosquito.
Cosmic rays have energies from 1 million eV to 300 million TeV.

The IBEX-Lo team consists of Lockheed Martin Advanced Technology Center, the University of New Hampshire, the Goddard Space Flight Center, and the Johns Hopkins University Applied Physics Laboratory.

Notes for Slide 43

In the configuration represented by the cutaway graphic, energetic neutral atoms enter the sensor from the top. Please note that while this drawing suggests that the entry system is only on one side of the detector, the entire detector is actually a circular doughnut shape. The entry system, called the “collimator”, blocks unwanted charged particles and stray light while selecting only Energetic Neutral Atoms for analysis. The entrance system also ensures that only particles that enter straight into the detector are analyzed so that an accurate determination of their direction of origin can be ascertained. These neutral particles are then turned into positive ions when they encounter the “ENA to Ion Conversion” material. As they are now ions, the path of each particle can be deflected into the rest of the detector. The “Electrostatic Analyzer” at the bottom of these cutaway graphics, reminiscent of the shape of the bottom of a Bundt cake pan, creates a magnetic field that forces the particles into a curved path. IBEX-Hi does not have the exact Time-of-Flight system as IBEX-Lo does, but IBEX-Hi does determine particle velocities using the instrumentation in the middle. The velocity of the particles indicates the energy of the particles. Over the course of one day, IBEX-Hi detects, on average, about 480 particles; during that same amount of time, IBEX-Lo detects, on average, about 60 to 100 particles. There are variations in the sensitivity of both detectors, and variations in the number of ENAs emitted by different parts of the sky. For example, at the 1 keV energy level, one portion of the sky known as the “IBEX Ribbon” has shown a particle count rate that is three times higher than that detected over the rest of the sky. Information about the IBEX Ribbon can be found on slides 47 to 58.

IBEX-Hi can detect particles with energies ranging from 300 eV to 6,000 eV (.3 keV to 6 keV) in 6 energy bands. The minimum energy level for Energy Level 1, also called Energy Step 1, is 0.30 keV. The maximum energy level for Energy Step 1 is 0.55 keV. The minimum energy level for Energy Step 2 is 0.53 keV. The maximum energy level for Energy Step 2 is 1.10 keV. The minimum energy level for Energy Step 3 is 0.90 keV. The maximum energy level for Energy Step 3 is 1.85 keV. The minimum energy level for Energy Step 4 is 1.70 keV. The maximum energy level for Energy Step 4 is 2.80 keV. The minimum energy level for Energy Step 5 is 2.35 keV. The maximum energy level for Energy Step 5 is 3.80 keV. The minimum energy level for Energy Step 6 is 3.80 keV. The maximum energy level for Energy Step 6 is 6.10 keV.

For comparison:
Visible light photons have electron volt energies of 1.5 to 3.5 eV.
13.6 eV is the energy required to ionize one atom of hydrogen.
High energy diagnostic medical X-ray photons have energies of around 200,000 eV (0.2 MeV).
1 TeV (1 trillion electron volts) is the energy of motion of a flying mosquito.
Cosmic rays have energies from 1 million eV to 300 million TeV.

The IBEX-Hi team consists of Los Alamos National Laboratory, the University of New Hampshire, and Southwest Research Institute.

Notes for Slide 44

The IBEX spacecraft spins once in about 15 seconds, allowing the IBEX-Hi and IBEX-Lo sensors to "see" the same parts of the sky at almost exactly the same time. IBEX repeatedly images the same strip of sky during a single orbit of Earth. During the next orbit, a strip of sky adjacent to the previous strip is imaged. The strips build up one by one so that after six months, the entire sky is imaged. The direction and amount of particles in each of the energy bands are recorded in each part of the sky over the course of six months, allowing a map of the data to be made.

To explain the movie clip associated with this slide: The yellow object in the middle is the Sun, the blue dot is the Earth, and the tiny dot orbiting the Earth is IBEX (Sun, Earth, and IBEX are not to scale). IBEX orbits Earth, and Earth orbits the Sun. As IBEX orbits Earth, the IBEX-Hi and Lo sensors "look" in opposite directions as the spacecraft spins (the spinning of the spacecraft is not shown, as it would occur much too quickly to be shown in this animation). The field of view of the IBEX sensors is represented by the two tan-colored "cones" stretching outward from the spacecraft. IBEX knows in which direction it is facing and the direction from which the particles came that it is able to detect. As IBEX orbits Earth and Earth orbits the Sun through an entire year, IBEX's sensors sweep across the whole sky, allowing a map to be built from the data one strip at a time, and a map of the entire sky is created every six months. The movie indicates a simulation of the "building" of a map. The image inset is from the first set of heliosphere maps released by the IBEX team in October 2009. Note that the oval shape of the map is due to the fact that this is a representation of a spherical sky on a flat map.

Notes for Slide 45

There are no additional notes for this slide.

Notes for Slide 46

There are no additional notes for this slide.

Notes for Slide 47

There are no additional notes for this slide.

Notes for Slide 48

For the full range of images released by the IBEX team so far, go to the IBEX website: http://www.ibex.swri.edu. Various explanations and releases can also be found in the Archived Updates section of the IBEX website.

Notes for Slide 49

To describe how something works, scientists develop models based on the evidence they have. Scientists collect more evidence to refine their models but sometimes the new data does not fit. Scientists then have to change and refine their models to fit the evidence, and often more observations are needed to help resolve the differences.

There are three maps shown here illustrating three possible simulations of the distribution of Energetic Neutral Atoms (ENAs) coming from the boundary of our Solar System. The reason for creating three of them is because the scientists were not sure, prior to IBEX, what the conditions were like at our Solar System's boundary. Depending on the conditions, the resulting maps would differ from each other a bit.

Notes for Slide 50

For an explanation of Energetic Neutral Atoms (ENAs), please refer back to the Notes section of slide 40.

The image on this slide shows one of the first IBEX heliosphere boundary maps at an energy band detected by IBEX-Hi. The image uses data collected over the course of six months between December 25, 2008 and June 18, 2009. In this map, red indicates the highest number (or flux) of energetic neutral atoms (ENAs) measured by the spacecraft. Yellow and green indicate lower numbers of ENAs, and blue and purple show the lowest number of ENAs detected by IBEX. The image is oval-shaped because it is illustrating a spherical-shaped sky as a flat map.

Quite unexpectedly, IBEX detected an arc-shaped region in the sky that is creating a large amount of ENAs, showing up as a bright, narrow “ribbon” on the maps, colloquially called the “IBEX Ribbon”. The IBEX Ribbon was a complete surprise and was not predicted by any of the models considered by the scientists prior to launch. The task of the scientists is to figure out what is causing this region of enhanced ENA emissions and how distant this region is from us.

Notes for Slide 51

The images on this slide show a comparison of one image from the first set of IBEX heliosphere boundary maps and one image from the second set of maps at the same energy level, six months apart. Each image uses data collected over the course of six months. In each map, red indicates the highest number of ENAs measured by the spacecraft. Yellow and green indicate lower numbers of ENAs, and blue and purple show the lowest number of ENAs detected by IBEX. The image is oval-shaped because it is illustrating a spherical-shaped sky as a flat map. These images were created using data from IBEX-Hi.

In the first set of IBEX heliosphere images, quite unexpectedly, IBEX detected an arc-shaped region in the sky that is creating a large amount of ENAs, showing up as a bright, narrow "ribbon" on the maps, colloquially called the "IBEX Ribbon". The maps on the left represent the first six months of ENAs that the IBEX spacecraft collected between December 25, 2008 and June 18, 2009. The maps on the right represent the second six months of ENAs that the IBEX spacecraft collected between June 18, 2009 and December 10, 2009. The large-scale IBEX Ribbon structure is generally stable between the two sets of maps, meaning the overall sky pattern of ENAs and the ribbon are still present, though the IBEX team noted some remarkable changes that show that the region producing the ribbon evolved, even over this short six-month timescale.

These images look different from the first heliosphere map image shown on slide 50. As the mission has evolved, the science team has refined their techniques for illustrating and mapping the IBEX data. Thus, the very first set of images look different, but fundamentally, the data itself is still the same. Also, the black and white areas on the right are due to the fact IBEX has a difficult time seeing that portion of the sky because it is blocked by the Earth's magnetosphere.

Notes for Slide 52

The images on this slide show a comparison of one image from the first set of IBEX heliosphere boundary maps and one image from the second set of maps at the same energy level, six months apart. Each image uses data collected over the course of six months. In each map, red indicates the highest number of ENAs measured by the spacecraft. Yellow and green indicate lower numbers of ENAs, and blue and purple show the lowest number of ENAs detected by IBEX. The image is oval-shaped because it is illustrating a spherical-shaped sky as a flat map. These images were created using data from IBEX-Hi.

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These images look different from the first heliosphere map image shown on slide 50. As the mission has evolved, the science team has refined their techniques for illustrating and mapping the IBEX data. Thus, the very first set of images look different, but fundamentally, the data itself is still the same region producing the ribbon evolved, even over this short six-month timescale.

Notes for Slide 53

The images on this slide show a comparison of one image from the first set of IBEX heliosphere boundary maps and one image from the second set of maps at the same energy level, six months apart. Each image uses data collected over the course of six months. In each map, red indicates the highest number of ENAs measured by the spacecraft. Yellow and green indicate lower numbers of ENAs, and blue and purple show the lowest number of ENAs detected by IBEX. The image is oval-shaped because it is illustrating a spherical-shaped sky as a flat map. These images were created using data from IBEX-Hi.

In the first set of IBEX heliosphere images, quite unexpectedly, IBEX detected an arc-shaped region in the sky that is creating a large amount of ENAs, showing up as a bright, narrow “ribbon” on the maps, colloquially called the “IBEX Ribbon”. The maps on the left represent the first six months of ENAs that the IBEX spacecraft collected between December 25, 2008 and June 18, 2009. The maps on the right represent the second six months of ENAs that the IBEX spacecraft collected between June 18, 2009 and December 10, 2009. The large-scale IBEX Ribbon structure is generally stable between the two sets of maps, meaning the overall sky pattern of ENAs and the ribbon are still present, though the IBEX team noted some remarkable changes that show that the region producing the ribbon evolved, even over this short six-month timescale.

These images look different from the first heliosphere map image shown on slide 50. As the mission has evolved, the science team has refined their techniques for illustrating and mapping the IBEX data. Thus, the very first set of images look different, but fundamentally, the data itself is still the same.

Notes for Slide 54

The images on this slide show a comparison of one image from the first set of IBEX heliosphere boundary maps and one image from the second set of maps at the same energy level, six months apart. Each image uses data collected over the course of six months. In each map, red indicates the highest number of ENAs measured by the spacecraft. Yellow and green indicate lower numbers of ENAs, and blue and purple show the lowest number of ENAs detected by IBEX. The image is oval-shaped because it is illustrating a spherical-shaped sky as a flat map. These images were created using data from IBEX-Hi.

In the first set of IBEX heliosphere images, quite unexpectedly, IBEX detected an arc-shaped region in the sky that is creating a large amount of ENAs, showing up as a bright, narrow "ribbon" on the maps, colloquially called the "IBEX Ribbon". The maps on the left represent the first six months of ENAs that the IBEX spacecraft collected between December 25, 2008 and June 18, 2009. The maps on the right represent the second six months of ENAs that the IBEX spacecraft collected between June 18, 2009 and December 10, 2009. The large-scale IBEX Ribbon structure is generally stable between the two sets of maps, meaning the overall sky pattern of ENAs and the ribbon are still present, though the IBEX team noted some remarkable changes that show that the region producing the ribbon evolved, even over this short six-month timescale.

These images look different from the first heliosphere map image shown on slide 50. As the mission has evolved, the science team has refined their techniques for illustrating and mapping the IBEX data. Thus, the very first set of images look different, but fundamentally, the data itself is still the same.

Notes for Slide 55

The images on this slide show a comparison of one image from the first set of IBEX heliosphere boundary maps and one image from the second set of maps at the same energy level, six months apart. Each image uses data collected over the course of six months. In each map, red indicates the highest number of ENAs measured by the spacecraft. Yellow and green indicate lower numbers of ENAs, and blue and purple show the lowest number of ENAs detected by IBEX. The image is oval-shaped because it is illustrating a spherical-shaped sky as a flat map. These images were created using data from IBEX-Hi.

In the first set of IBEX heliosphere images, quite unexpectedly, IBEX detected an arc-shaped region in the sky that is creating a large amount of ENAs, showing up as a bright, narrow “ribbon” on the maps, colloquially called the “IBEX Ribbon”. The maps on the left represent the first six months of ENAs that the IBEX spacecraft collected between December 25, 2008 and June 18, 2009. The maps on the right represent the second six months of ENAs that the IBEX spacecraft collected between June 18, 2009 and December 10, 2009. The large-scale IBEX Ribbon structure is generally stable between the two sets of maps, meaning the overall sky pattern of ENAs and the ribbon are still present, though the IBEX team noted some remarkable changes that show that the region producing the ribbon evolved, even over this short six-month timescale.

These images look different from the first heliosphere map image shown on slide 50. As the mission has evolved, the science team has refined their techniques for illustrating and mapping the IBEX data. Thus, the very first set of images look different, but fundamentally, the data itself is still the same.

Notes for Slide 56

In the first set of heliosphere maps, the IBEX team saw a bright “knot” of energetic neutral atoms (ENAs) in the upper left (northern) portion of the ribbon. This map cutout at the top shows the knot region from the first set of maps, and the middle one shows the same region in the second set of maps. Red, orange, and yellow colors indicate regions emitting higher numbers of ENAs (the “knot); green and blue colors indicate lower numbers of ENAs. In the middle cutout, the much smaller bulge of red and the greater use of yellows and greens in the map tells the science team that the knot area emitted fewer ENAs during the time period of the second set of maps, though a smaller portion of the knot did seem to emit more ENAs in the second map cutout, as shown by the one red pixel. The knot seems to have spread out a bit, as well, in the second map cutout. The red outline has been added to highlight this area in both cutout maps.

The “difference image” in the lowest box shows the difference in emissions between the first and second maps above. The lighter blue region in this difference image tells the scientists that this region has emitted fewer ENAs, overall, in the second six months of data collection.

Notes for Slide 57

IBEX has made the first direct observations of interstellar neutral atoms—hydrogen and oxygen atoms drifting in from the interstellar medium outside of our heliosphere. In each map, red indicates the highest number of energetic neutral atoms (ENAs) measured by the spacecraft. Yellow and green indicate lower numbers of ENAs, and blue and purple show the lowest number of ENAs detected by IBEX. The concentration of red and yellow in this image shows the hydrogen (top image) and oxygen (bottom image) detected by IBEX. This image was released in October 2009.

Notes for Slide 58

The IBEX map has been superimposed on the heliopause, which is a possible location for the origin of the IBEX ribbon. The gray horizontal arrow in the image above indicates the direction of travel of our Solar System through space.

Notes for Slide 59

This is an artist's representation of Earth's magnetosphere. Earth is represented near the middle. The lines around the Earth are model magnetic field lines in Earth's magnetosphere. Our Sun is well off of the edge of the drawing to the left. The pink area in front of Earth's magnetopause is the region where IBEX has detected energetic neutral atoms. As the solar wind streams outward from the Sun at a million miles per hour (1.6 million kilometers per hour), the solar wind protons and electrons pile up along the outer boundary of Earth's magnetosphere, called the "magnetopause". These charged particles are shocked, heated, and slowed almost to a stop before getting diverted sideways. A few of those charged particles interact with neutral atoms in the very outer reaches of our atmosphere about 35,000 miles (56,000 kilometers) from the surface of the Earth. This extremely low-density region of our atmosphere, called the "exosphere" (shown as the blue fuzzy region around the Earth), extends beyond Earth's protective magnetic field. The solar wind charged particles exchange electrons with our exosphere's neutral particles, and the solar wind particles become neutral in the process. Now, they are no longer affected by Earth's magnetic field and fly off in whatever direction they were going when they became neutral. Because some of these particles happen to be traveling in the direction of the IBEX spacecraft and its sensors, IBEX can detect them. Just like our heliosphere boundary, our magnetosphere boundary does not give off light that we can detect, so we must use particle sensors like those of IBEX to study regions like this. IBEX detected ENAs from this process in March and April 2009.

All planets with magnetic fields have magnetospheres, and the solar wind blows them into a wind-sock-shape with the tail pointing away from the Sun. Similarly, our Solar System's heliosphere is believed to be a similar structure, with the tail blowing away from the direction of travel of our Solar System. The solar wind and interstellar medium strengths are variable, so the boundaries do move. IBEX can help us understand our heliosphere as well as some of the processes occurring our Earth's magnetosphere.

Notes for Slide 60

As the solar wind streams outward from the Sun, the solar wind protons and electrons pile up along the outer boundary of Earth’s magnetosphere, called the “magnetopause”. These charged particles are shocked, heated, and slowed almost to a stop before getting diverted sideways. A few of those charged particles interact with neutral atoms in the very outer reaches of our atmosphere. The solar wind charged particles exchange electrons with our exosphere’s neutral particles, and the solar wind particles become neutral in the process (energetic neutral atoms, or ENAs). The area where the exosphere and solar wind interact most heavily produces the most ENAs. This new IBEX map shows the ENAs that are created due to interaction between the solar wind and Earth’s magnetosphere. The ENAs are created in greater numbers at the magnetosphere boundary in the direction pointing toward the Sun (to the right, well off the edge of this map) and thin out at locations away from this point. Earth is shown by the black/white circle to the left. The lines that curve around the Earth represent model magnetic field lines in the Earth's magnetosphere. Red and yellow colors in the map above show areas with the most ENAs; green and blue colors show areas with the least ENAs. These key observations were made in March and April 2009 when IBEX’s detectors could scan the region directly in front of the magnetopause.

Explanation of labels in the image:
“**IBEX-Hi (0.7 – 6 keV)**” means that IBEX-Hi data was used in the creation of this image in the energy range of 0.7 to 6 keV. “**2009-03-28, 04:54 – 15:54 UT**” indicates that this data was taken on March 28, 2009 from 4:54 to 15:54 Universal Time (11:54 p.m. ET on March 27 to 10:54 a.m. ET on March 28, 2009). “**Counts in 96 spins per 6-deg-bin**” indicates that the IBEX data was compiled from a swath of sky 6 degrees wide, which is the field of view of the IBEX sensors (the amount of sky that they can “see” at once), and the particle counts were added up in “bins” or chunks of 96 spins of the IBEX spacecraft. IBEX spins once in about 15 seconds, and 96 spins lasts about 24 minutes. The numbers next to the color bar on the right show the total particle counts for each color in the color bar. “**Z [Re]”** is the distance, in units of Earth radii, either north of the Earth’s north pole (the positive numbers) or south of the south pole (the negative numbers). “**X [Re]**” is the distance, in units of Earth radii, in front of the Earth toward the Sun.

Notes for Slide 61

This image is a composite image of the plasma sheet in the Earth's magnetotail. Earth is shown by the black/white circle in the middle. The curved lines represent model magnetic field lines in the Earth's magnetosphere. The Sun is toward the left, well off the edge of the image. The red and yellow colors show the regions of the magnetosphere emitting the most energetic neutral atoms (ENAs), and the green, blue, and purple colors show the regions emitting fewer ENAs. This image represents the ENAs collected by IBEX from October 27 to 29, 2009. The line next to FOV in the lower right corner shows the width of IBEX's field of view at any one time. It is important to note that this ENA image is not a snapshot, but was built up by IBEX with the ENAs detected and averaged over about two days.

Notes for Slide 62

This image is a composite image of the plasma sheet in the Earth's magnetotail. Earth is shown by the black/white circle in the middle. The curved lines represent model magnetic field lines in the Earth's magnetosphere. The Sun is toward the left, well off the edge of the image. The red and yellow colors show the regions of the magnetosphere emitting the most energetic neutral atoms (ENAs), and the green, blue, and purple colors show the regions emitting fewer ENAs. This image represents the ENAs collected by IBEX in Orbit 52, from November 5 through 7, 2009. The line next to FOV in the lower right corner shows the width of IBEX's field of view at any one time. It is important to note that this ENA image is not a snapshot, but was built up by IBEX with the ENAs detected and averaged over about two days. Notice there are more ENAs that can be seen in the most distant part of the plasma sheet to the far right, and fewer ENAs are seen in the nearer plasma sheet region, as compared to the image on Slide 60. Such a brightening would be consistent with dynamic changes in the magnetotail (it is recommended that the viewer toggle back and forth between the slides to see the differences). Scientists know these changes occur frequently. There are several possibilities to explain the variation in ENAs in the distant plasma sheet. A closer look at the various images produced by multiple IBEX orbits has revealed what appears to have been a piece of the plasma sheet being bitten off and ejected down the tail. This is called a "magnetic disconnection", a dynamic event where the magnetic fields "reconnect" across the plasma sheet. Imagine the magnetosphere as a long balloon used for "tying" animal shapes. If you squeeze the balloon with your hands, the squeezing pressure forces the air into another segment of the balloon. Similarly, the solar wind sometimes increases the pressure around the magnetosphere, resulting in a portion of the plasma sheet being pinched away from the rest and forced down the magnetotail - just like squeezing forces air to move away from the pinched part of the balloon. This ejected material is called a "plasmoid". Scientists have never been able to see a magnetic disconnection event in any actual images, so the IBEX team is excited that IBEX may very well have spotted one for the first time. Another possibility that the team is considering is an increase in solar wind pressure that would squeeze the magnetotail and cause it to heat up. This process would also create more ENAs in the plasma sheet in a similar pattern to what IBEX has seen. A third hypothesis is that plasma may have been forced toward Earth, coming inward from farther away in the magnetotail. The evidence for this, though, is not as strong based on the conditions in and around the magnetosphere at the time of these observations.

Notes for Slide 63

Over the course of 11 years, the Sun's magnetic activity level increases gradually and peaks. The peak is called "solar maximum". At solar maximum, the number and frequency of solar activity in the form of flares, prominences, and sunspots is generally at its highest. The magnetic activity of the Sun decreases gradually to a point called "solar minimum", when there are fewer (and sometimes no) sunspots and little solar flare or prominence activity. We have exited an extended solar minimum. The next solar maximum is predicted to occur in the next few years.

Notes for Slide 64

There are no additional notes for this slide.

Notes for Slides 65 through 69

Slide 65: The “Achieving Orbit” activity is available for download from the IBEX website: http://www.ibex.swri.edu/planetaria/index.shtml.

Slide 66: The “Particle Detection” activity is available for download from the IBEX website: http://www.ibex.swri.edu/planetaria/index.shtml.

Slide 67: “The Heliosphere” lithograph is available for download in English and in Spanish from the IBEX website: http://www.ibex.swri.edu/planetaria/index.shtml.

Slide 68: “Four of the States of Matter” and “Mystery Matter” are available for download from the IBEX website: http://www.ibex.swri.edu/planetaria/index.shtml.

Slide 69: The “Postcards from Space” lesson plan and postcard are available for download from the IBEX website: http://www.ibex.swri.edu/planetaria/index.shtml.

Notes for Slide 70

Posters and lithographs are available for download from the IBEX website: http://www.ibex.swri.edu/planetaria/index.shtml.

Information about the “IBEX: Search for the Edge of the Solar System” planetarium show is available at http://www.ibex.swri.edu/planetaria/ibexshow.shtml.

The Games and Activities page on the IBEX website is available at http://www.ibex.swri.edu/games/index.shtml.

Notes for Slide 71

The NASA Portal Page web address is http://www.nasa.gov/ibex.

The IBEX Mission Site web address is http://www.ibex.swri.edu.

Notes for Slide 72

There are no additional notes for this slide.

Slide 72 is the final slide in the original set.

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