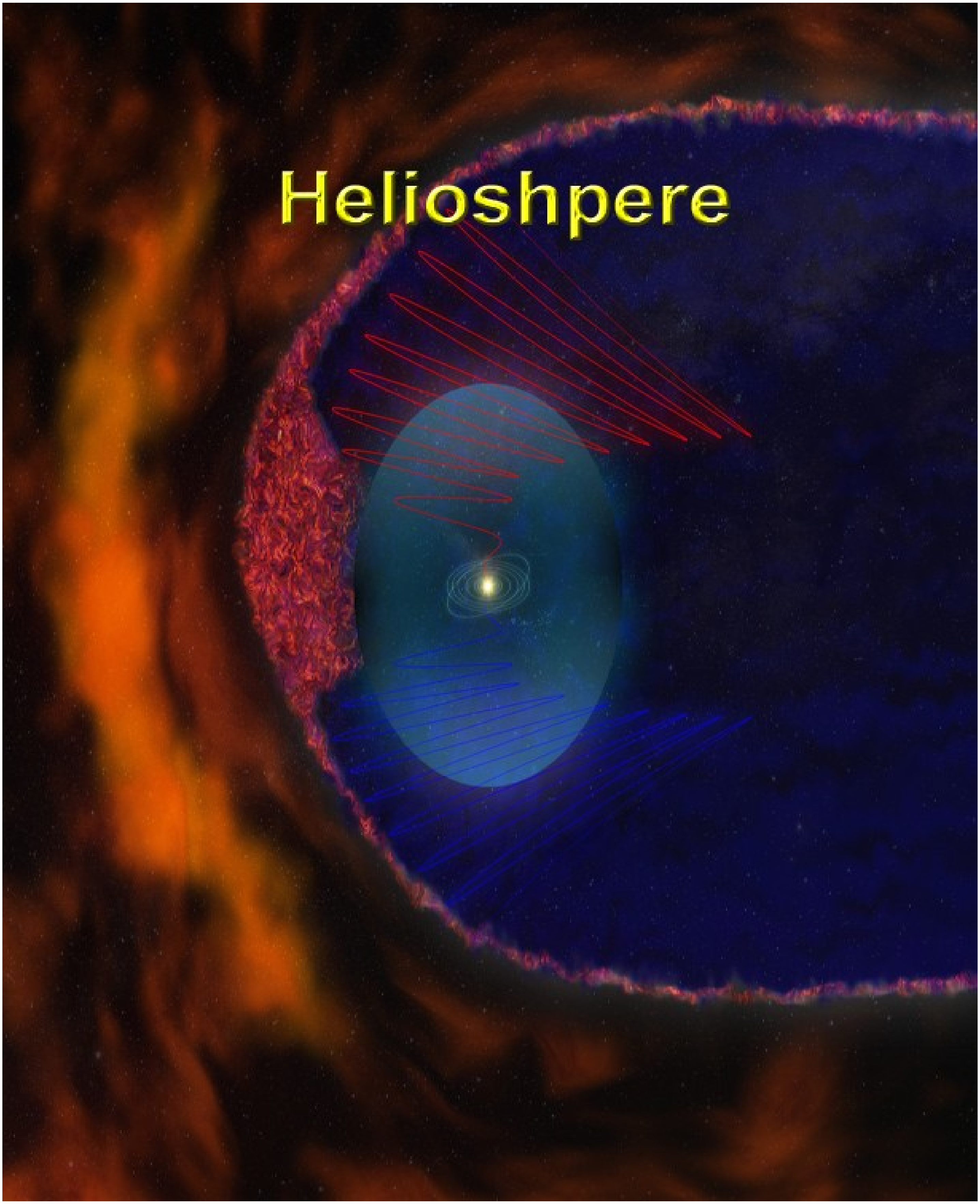

Helioshpere

The Heliosphere

***{Abstract** – In this segment of our video book, we cover the Sentinels of the Heliosphere fleet; the distance to the edge of our Sun's solar wind; and the Aurora Borealis.*

We start by defining the limits of the Sun's influence, including the Termination Shock, Heliopause or Heliosheath, and Bow Shock. The Voyager 1 and Voyager 2 progress are reviewed.

Next, we cover the near-Earth fleet of satellites Hinode, RHESSI, TRACE, and FAST; the Magnetosphere satellites Cluster 1 through 4 plus Geotail; the Sun observers Stereo A and Stereo B; the solar wind observers orbiting Lagrange Point 1 – ACE, Wind, and SOHO; and back to the Magnetosphere with THEMIS A through E; and back again to Voyager 1 and 2. We conclude with a look at the big November 2011 solar storm observed by Stereo.

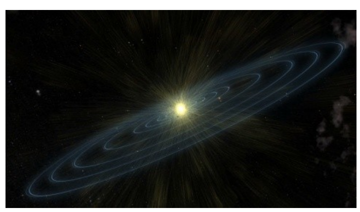
We then cover the nature of the aurora Borealis and aurora Australis. This includes the Bohr atomic model where we explain the quantum jumps in high altitude Oxygen atoms that create photons.

Next we review of the Solar System distances we have covered in this and the previous segments.

We conclude the Solar System chapter of our video book with Carl Sagan's "Pail blue dot" speech with spectacular views of Earth as the backdrop.}

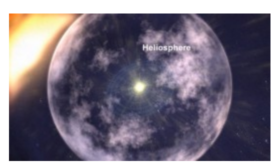
Heliosphere

The sun is moving through the galactic medium like a ship in the ocean. We are just tagging along.



As we discussed earlier, the Sun is a thermonuclear fireball that continually ejects large quantities of highly energetic particles into space. This is the Solar Wind, and it goes out in all directions.

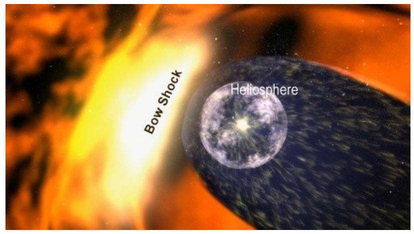
[Music: *James Horner's "Braveheart – End Credits": This beautiful music with its lonely bagpipes sound fits the wondering through empty space that all our unmanned spacecraft do, year in and year out.***]**



The extent of the solar wind defines the final frontier of the influence of the Sun. It's called the Heliosphere.

The solar wind's strength dies down as it is spread over ever increasing volumes of space **[**the inverse square rule applies once again**]**. Once it equals the strength of the interstellar wind coming from the rest of the Milky Way, a stalemate is reached. This is called the Termination Shock. The high velocity particles from the sun come to a veritable standstill in a stalemate with the rest of the galactic medium.

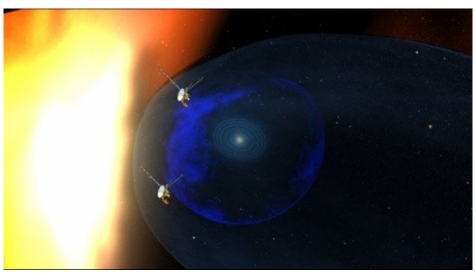
The wide area of space where the transition from solar wind to galactic wind occurs is called the Heliosheath or Heliopause.



Like ocean water being pushed aside by the bow of a great ship, the Sun with its solar wind does the same in the galactic medium. That's why they call the final boundary the Bow Shock. This marks the final extent of the solar wind and defines the outer limits of the Heliosphere.

Unlike the other objects in the solar system that can be seen and triangulated to determine how far away they are, the only sure way to find out how far away the Termination and Bow Shocks are, and therefore calculate the full size of the solar system, is to go there, measure which way the wind is blowing, and report back how far you've gone.

Voyager



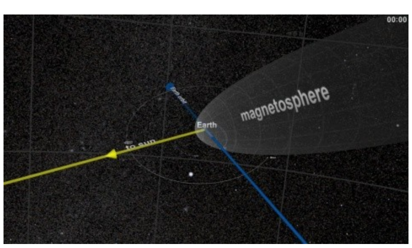
This is exactly what Voyager 1 and Voyager 2 have done. Launched in 1977, both spacecraft have passed through the Termination Shock. Voyager 2 is currently deep into the Heliosheath.

I'll tell you where Voyager 1 is a bit later in this segment.

Sentinels of the Heliosphere

We now know that the Heliosphere is not exactly a sphere. It is squashed by the galactic wind. At the squashed end, we know it extends to around 11 billion miles from the sun. That's 118 times further than the distance between the Earth and the Sun. It takes light around 16 hours to get from the Sun to the Heliosheath.

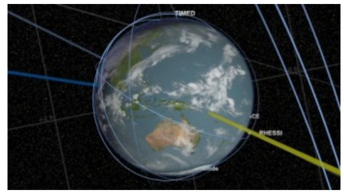
NASA's Goddard Space Flight Center in cooperation with international partners manages a fleet of spacecraft monitoring all aspects of the Heliosphere. This fleet is called the Sentinels of the Heliosphere.



The gray mesh around the Earth is called the Magnetosphere. It is the Earth's magnetic field, pushed back by the Solar Wind. It is critical for life on Earth because it routes charged particles in the wind around the earth instead of letting it bombard us head on. That makes it important for us to understand.

Near-Earth Fleet

Here's the Near-Earth Fleet. It's monitoring solar activity and orbiting Earth once every 92 minutes.



[Additional info:

Hinode (Sunrise) observes the Sun in multiple wavelengths up to x-rays, and is improving our understanding of the mechanisms that power the solar atmosphere and drive solar eruptions.

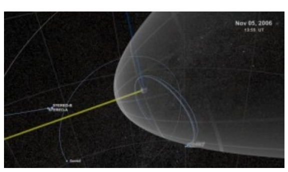
RHESSI : Observes the Sun in x-rays and gamma-rays to explore the basic physics of particle acceleration and explosive energy release in solar flares.

TRACE: Observes the Sun in visible and ultraviolet wavelengths.

TIMED: Studies the upper layers of the Earth's atmosphere: the Thermosphere, Ionosphere, and Mesosphere (40-110 miles up).

FAST: Measures particles and fields in regions where aurora borealis form to study the microphysics of space plasma and the accelerated particles that cause the aurora.**]**

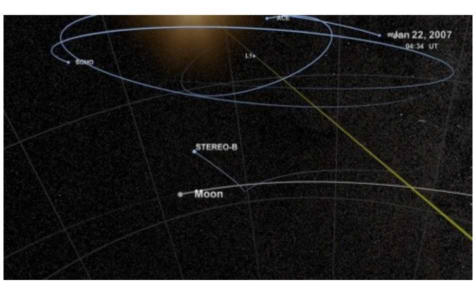
Geospace Fleet



Now we are taking a look at the Geospace Fleet that orbits deep into and around the Magnitosphere.

Cluster is a group of four satellites that fly in formation to measure the three dimensional boundaries of the Magnitosphere as it interacts with the Solar Wind.

Geotail conducts measurements of electrons and ions in the Earth's magnetotail – the Magnitosphere pushed back by the solar wind.

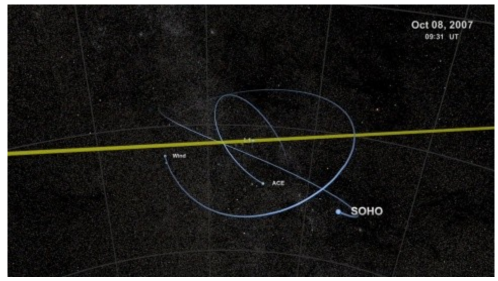


STEREO-A and B observe the Sun, with imagers and particle detectors, off the Earth-Sun line, providing a three-dimensional view of solar activity. Watch how they used the moon to set themselves apart at the best distance to view the Heliosphere.

L1 Fleet

Here we see the L1 Fleet: - orbiting the Lagrange Point 1 between the Earth and the Sun. L1 is the point between the Earth and the Sun where the gravitational pull is approximately equal in both directions.

Spacecraft can orbit this location for continuous coverage of the Sun. (You may remember the Trojan Asteroids of Earth, Jupiter and Neptune that orbit other Lagrange Points that we discussed earlier). Out here, there is no Magnetosphere, so a good look at the Solar Wind is possible.

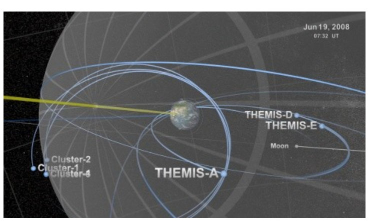


[Music: *James Horner's "Braveheart – Main Title": We continue with this music theme.***]**

<u>Wind</u>: Measures particle flows and fields in the solar wind.

<u>ACE</u> Advanced Composition Explorer: Measures the composition and characteristics of the solar wind.

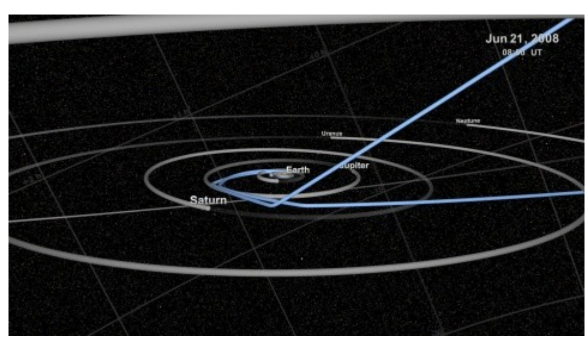
<u>SOHO</u>, is the famous Solar & Heliospheric Observatory studies the Sun from its deep core to the outer corona and the solar wind. I'll show you what it sees when there is a solar flare following this clip.



Here we see the <u>THEMIS</u> fleet of five satellites that study how magnetospheric instabilities produce the aurora borealis, also known as substorms.

Heliopause Fleet

The Heliopause fleet is Voyager 1 and 2. These spacecraft conducted the original 'Planetary Grand Tour' of the solar system in the 1970s and 1980s. They have now travelled further than any human-built spacecraft and are still returning measurements of the Heliosphere.

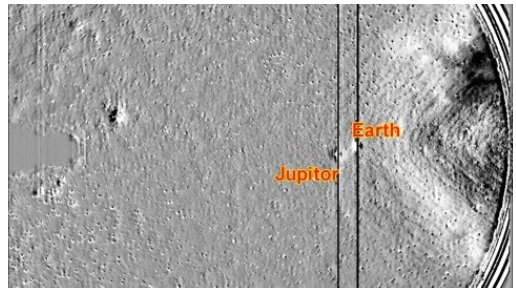


Solar Flares

Remember STEREO - two space-based observatories - one ahead of Earth in its orbit, the other trailing behind. With this new pair of viewpoints, scientists can see the structure and evolution of solar storms as they blast from the Sun and move out through space.

A **coronal mass ejection** (CME) with a broad front blasted from the Sun and headed towards Earth (Nov. 26-28, 2011). STEREO caught the action.

The particle cloud (darker mass) can be seen buffeting Earth late on Nov. 28th. Without the STEREO instrument we would not be able to see the track of solar storms like this one.

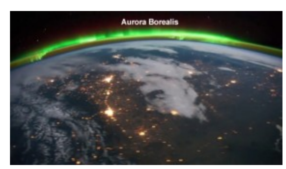


[Music: *Gabriel Fauré - Pavane Op.50. - For this Space Station view of the auroras, we repeat the music we used in "The Earth" segment for the Space Station's view of cities at night.***]**

Aurora Borealis

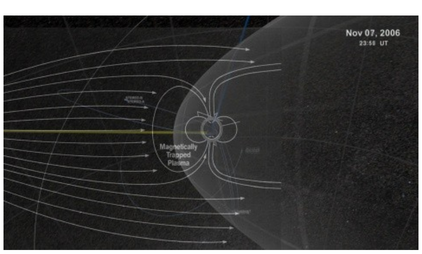
These solar storms with their coronal mass ejections are responsible for the Aurora Borealis or Northern Lights and the aurora Australis, or the southern lights.

Here's a look at the aurora borealis and aurora Australis taken from the space station.



The aurora lights were a mystery for most of man's existence. It wasn't until our modern understanding of the magnetosphere via satellite observations in the second half of the 20th century was combined with Quantum Mechanics developed in the first half of the 20th century that a real understanding was reached.

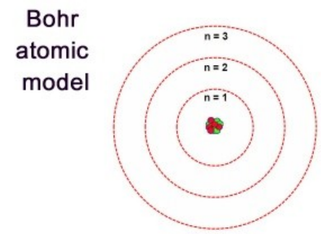
[Music: *James Horner's "Braveheart – Main Title": We return to Braveheart.***]**



What happens is that the Magnitosphere routes the solar wind charged particles along the Earth's magnetic field lines to the north and south polar regions. There, they collide with oxygen and nitrogen atoms in the Thermosphere.

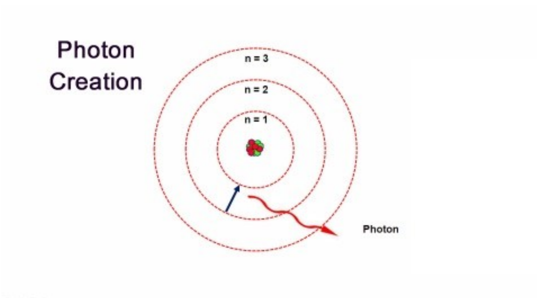
Quantum Mechanics explains how these collisions create light. I'll take a minute to explain this because it's relevant for understanding how a star's light can tell us how far away the star is.

Thanks to the work of Niels Bohr, a Danish physicist, we discovered that electrons attached to atoms occupy quantized discrete energy levels called shells. The further a shell is from the nucleus, the greater the energy level and the larger the quantum number.



And, thanks to Albert Einstein, we discovered that light was quantized as photons and that they were:

- Created when an electron drops from a higher to a lower energy level, sometimes referred to as taking a quantum leap.
- And absorbed when a photon collides with an atom and drives an electron to a higher energy level.



In the case of the Aurora, the high velocity particles from the solar wind collide with the oxygen and nitrogen atoms in the thermosphere driving electrons in these atoms to higher energy levels. When they drop back down, photons are created.

- For oxygen emissions we get mostly green light – the most common auroras.
- From nitrogen emissions we get mostly blue or red – rarer in that there is less nitrogen than oxygen at the very top of the atmosphere.

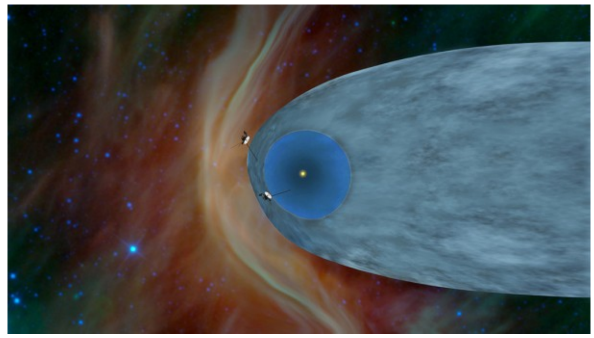
We'll go deeper into quantum mechanics and light at the beginning of our segment on distant stars.

Voyager 1 Enters Interstellar Space

Voyager 1 no longer has a working plasma sensor, so scientists needed a different way to measure the spacecraft's plasma environment to see if it was still in the Heliopause or had moved into the Bow Shock area in interstellar space. That's where the plasma density is expected to be 40 times greater than what we see inside the Heliosphere. But Voyager 1 can still measure the pitch of oscillations of the medium it is flying in.

In March 2012, a coronal mass ejection erupted from the sun. The solar storm that this CME created arrived at Voyager 1's location 13 months later, in April 2013. Voyager 1's plasma wave instrument detected the movement. Here's the sound of the oscillations.

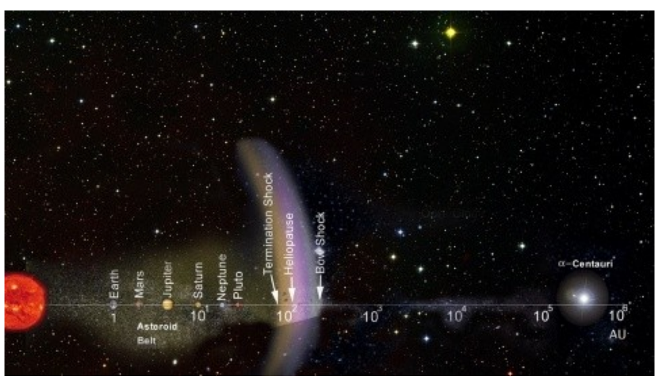
These particular oscillations meant the spacecraft was bathed in plasma more than 40 times denser than what they had encountered in the Heliopause. So at 12 billion miles, Voyager 1 was no longer in the Heliosphere! It was in interstellar space.



Although the Voyager craft will only transmit information to us for another decade or so, they will continue to wander in a billion year journey to the stars.

Solar System Review

Now that we have a feel for the size of the Heliosphere, let's review how far away the main objects in our Solar System are.



- The Sun is 93 million miles away and a millions earths could fit inside it.
- Jupiter, the largest planet in the Solar System is 5.2 times further away from the sun than the earth is. That puts its orbit 480 million miles away from ours.
- Pluto is 3 and a half billion miles away.
- We have just seen that the Termination Shock is 11 Billion miles away.
- And the Bow Shock is 12 billion miles away.
- We'll cover how far away our nearest stellar neighborhood system, Alpha Centauri, is in our next segment on Nearby Stars.

Pale Blue Dot

In the first segment, we learned just how vast the Earth is: how high the sky is; how far away the continents are across the great oceans of the world. But now that we've seen the enormous size of the Solar system, we can put Earth's size into this broader perspective.

Back in 1990, Carl Sagan requested that Voyager 1 be turned around to photograph Earth. It was only 4 billion miles away back then. The picture highlights just how small the Earth really is compared to the huge size of the Solar System. Here is the famous clip he created around this photograph. He expresses my feelings to a tee.

[Music: *Vangelis' "Heaven and Hell": This is the music Carl Sagan chose as the theme music for his entire 'Cosmos' series. It is repeated here and in other 'How far away is it' segments.*

"From this distant vantage point, the Earth might not seem of any particular interest. But for us, it's different. Consider again that dot. That's here. That's home. That's us. On it everyone you love, everyone you know, everyone you ever heard of, every human being who ever was, lived out their lives.

"The aggregate of our joy and suffering, thousands of confident religions, ideologies, and economic doctrines, every hunter and forager, every hero and coward, every creator and destroyer of civilization, every king and peasant, every young couple in love, every mother and father, hopeful child, inventor and explorer, every teacher of morals, every corrupt politician, every "superstar," every "supreme leader," every saint and sinner in the history of our species lived there – on a mote of dust suspended in a sunbeam. The Earth is a very small stage in a vast cosmic arena. Think of the rivers of blood spilled by all those generals and emperors so that in glory and triumph they could become the momentary masters of a fraction of a dot. Think of the endless cruelties visited by the inhabitants of one corner of this pixel on the scarcely distinguishable inhabitants of some other corner.

"How frequent their misunderstandings, how eager they are to kill one another, how fervent their hatreds. Our self-importance, the delusion posturings, our imagined that we have some privileged position in the universe, are challenged by this point of pale light. Our planet is a lonely speck in the great enveloping cosmic dark. In our obscurity – in all this vastness – there is no hint that help will come from elsewhere to save us from ourselves.

"The Earth is the only world known, so far, to harbor life. There is nowhere else, at least in the near future, to which our species could migrate. Visit, yes. Settle, not yet. Like it or not, for the moment, the Earth is where we make our stand.

"It has been said that astronomy is a humbling and character-building experience. There is perhaps no better demonstration of the folly of human conceits than this distant image of our tiny world. To me, it underscores our responsibility to deal more kindly with one another and to preserve and cherish the pale blue dot, the only home we've ever known."

—Carl Sagan, *Pale Blue Dot: A Vision of the Human Future in Space, 1997 reprint, pp. xv–xvi*