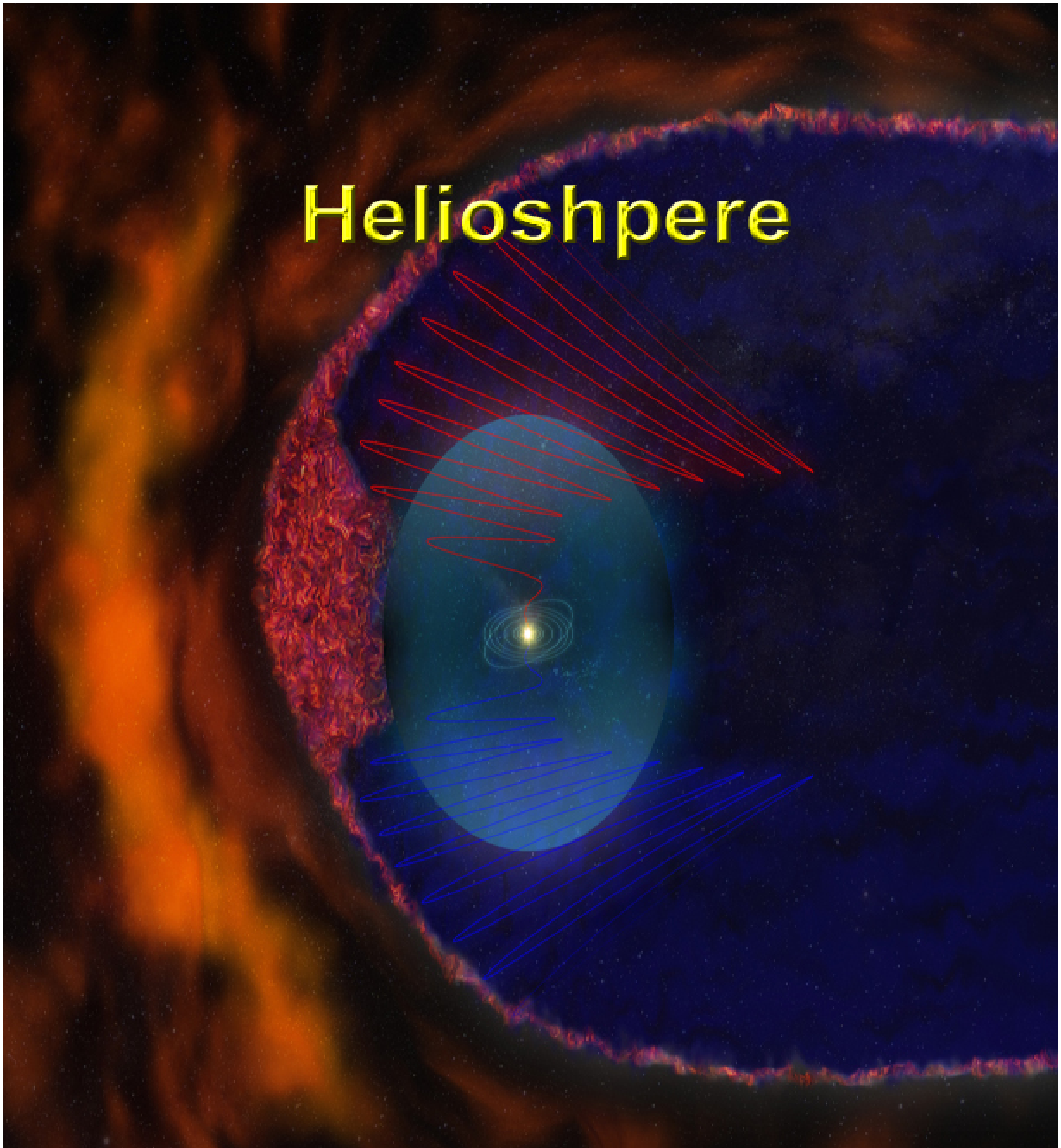

Helioshpere

Comets and 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; the Aurora Borealis, Comets, the Kuiper Belt and the Oort Cloud.*

We start by defining the limits of the Sun's influence, including the Termination Shock, Heliopause, Heliosheath, and the Bow Shock. Voyager 1 and Voyager 2 progress is 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 cover what a comet is and the history of comets including the Great Comet of 1577 studied by Tycho Brahe and the many comets that became Halley's Comet. We then examine comet orbits including the long period comets Siding Spring, Hale-Bopp and Lovejoy 2014, and the short period comets 67P, Encke and Halley's Comet.

These two kinds of comet orbits along with evaporating comets leads us to the Kuiper Belt and Oort Cloud as areas that generate new comets. We end the segment on comets with a look at Shoemaker Levy crashing into Jupiter and the Rosetta Mission to 67P.

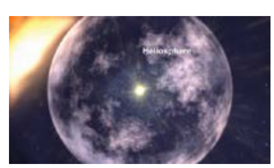
We conclude with a review of the Solar System distances we have covered in this and the previous segments.}

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.

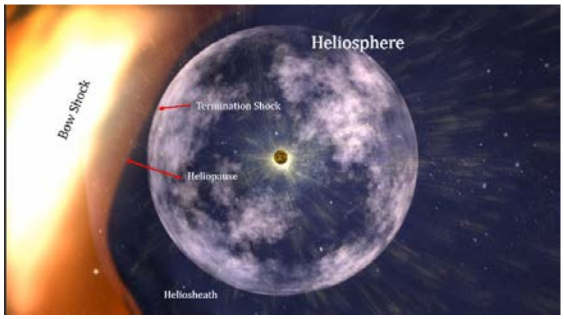
[Music @ 00:00 - *Williams, John: Braveheart End Credits; London Symphony Orchestra from the album "Braveheart - London 1995"***]**



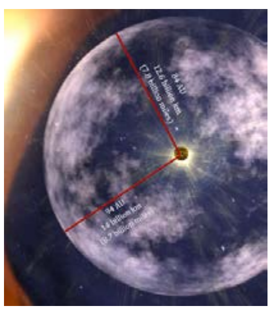
The extent of the solar wind defines the final frontier of the influence of the Sun. It's called the Heliosphere.

The solar wind's strength dies down as it is spread over ever increasing volumes of space [the inverse square rule applies once again]. As it approaches the strength of the interstellar wind coming from the rest of the Milky Way, its motion slows down abruptly. This is called the Termination Shock.

Beyond this, is a transitional region called the Heliosheath that terminates at the outermost edge of the heliosphere called the Heliopause. And, 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.

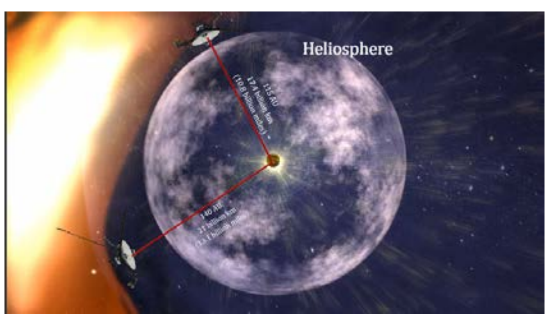


Unlike the other objects in the solar system that can be seen and triangulated to determine how far away they are, the only sure way to find out how far away the Termination and Bow Shocks are, and therefore calculate the full size of the solar system, is to go there, measure which way the wind is blowing,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

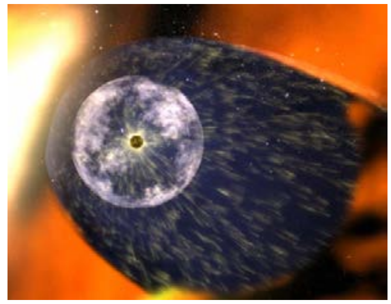


This is exactly what Voyager 1 and Voyager 2 have done. Launched in 1977, both spacecraft have passed through the Termination Shock. Voyager 1 crossed at 94 AU in December 2004. Voyager 2 crossed at 84 AU in August 2007. So we see that the boundary is not exactly a sphere.

As of October 2017, both Voyagers are deep into the Heliosheath. [After 40 years, their instruments still report on cosmic rays, charged particles, magnetic fields and plasma waves.] When they detect a change in the direction of the wind, we'll know that they have entered interstellar space. They are expected to have enough energy to continue reporting through 2020. So there is still a chance we'll see it happen.



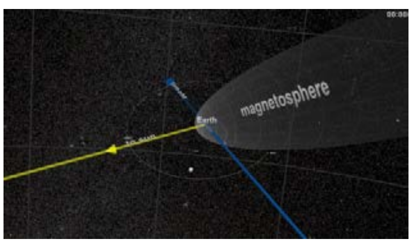
Recent magnetic field data from the Voyager probes, Cassini and IBEX the Interstellar Boundary Explorer mission indicate that the heliosphere may be more rounded than previously thought. If correct, the tail we see here would be replaced by the interstellar medium. Research is ongoing in this area.



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.

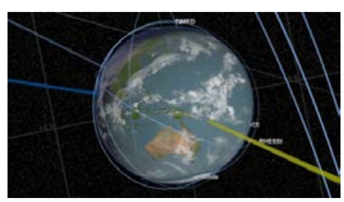
NASA's Goddard Space Flight Center in cooperation with international partners manages a fleet of spacecraft monitoring all aspects of the Heliosphere. This fleet is called the Sentinels of the Heliosphere.



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.

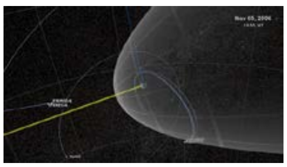
<u>RHESSI</u> : Observes the Sun in x-rays and gamma-rays to explore the basic physics of particle acceleration and explosive energy release in solar flares.

<u>TRACE</u>: Observes the Sun in visible and ultraviolet wavelengths.

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

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

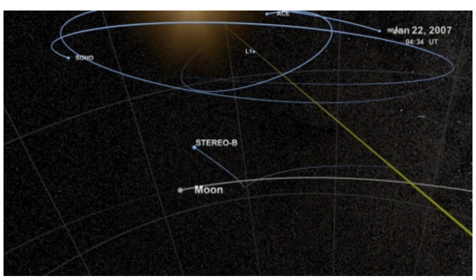
Geospace Fleet



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.



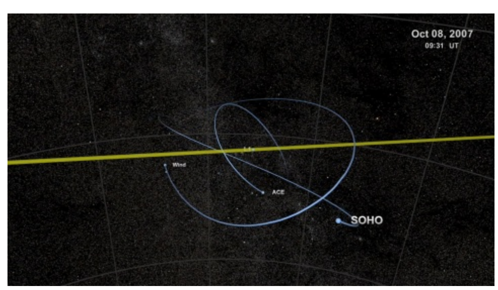
STEREO-A and B observe the Sun, with imagers and particle detectors, off the Earth-Sun line, providing a three-dimensional view of solar activity. Watch how they used the moon to set themselves apart at the best distance to view the Heliosphere.

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.

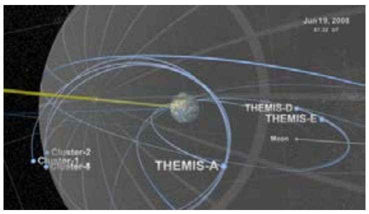
Spacecraft can orbit this location for continuous coverage of the Sun. (You may remember the Trojan Asteroids of Earth, Jupiter and Neptune that orbit other Lagrange Points that we discussed earlier). Out here, there is no Magnetosphere, so a good look at the Solar Wind is possible.



Wind: Measures particle flows and fields in the solar wind.

ACE Advanced Composition Explorer: Measures the composition and characteristics of the solar wind.

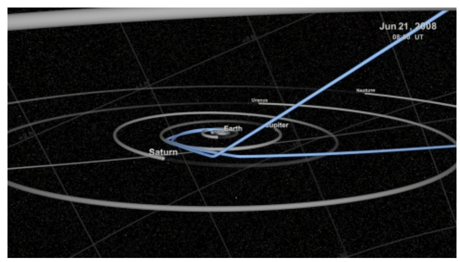
SOHO, is the famous Solar & Heliospheric Observatory studies the Sun from its deep core to the outer corona and the solar wind.



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

Heliopause Fleet

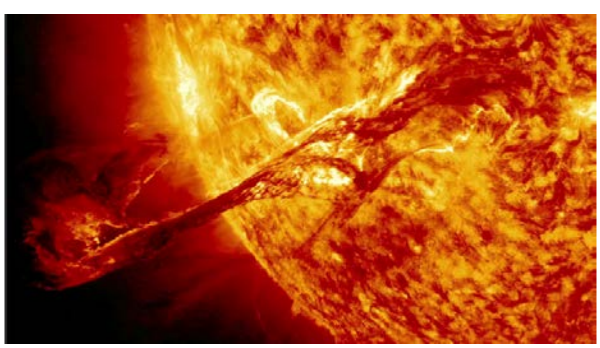
The Heliopause fleet is Voyager 1 and 2. Voyager 1 has traveled the furthest at 140 AU. That's a 140 times further away from the sun than we are. It takes light almost 19 and a half hours to reach it.



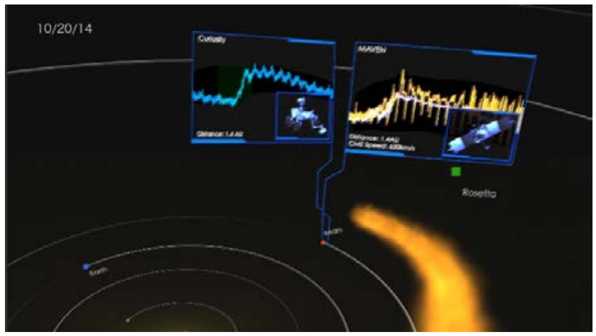
[Music @07:51 - *Debussy, Claude: Petite Suite, L.65 - 1. En bateau; Ernest Ansermet & L'Orchestre de la Suisse Romande; from the album "For the Hopeless Romantic", 2005]*

Solar Storms

Here's a solar storm that erupted on August 21st, 2012. It's like the one on October 14, 2014 that SOHO and other spacecraft tracked across the Solar System. This kind of storm is called a Coronal Mass Ejection (or CME for short). CMEs are billion-ton clouds of solar plasma launched by a single explosion. A typical velocity is around 300 km/s. That's 186 miles/s.



This 2014 CME washed over spacecraft throughout the inner solar system - including Curiosity on Mars and ESA's Rosetta orbiting comet 67P. Measuring these storms enables scientists to predicting a CME's path and strength. This is important because CMEs can disrupt communications and power systems on Earth if we are not prepared.

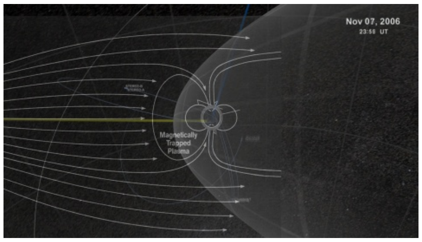


Aurora Borealis

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.

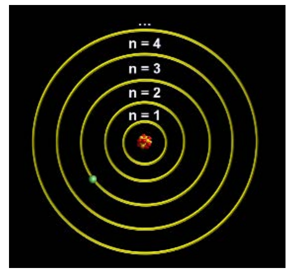
The aurora lights were a mystery for most of man's existence. It wasn't until our modern understanding of the magnetosphere via satellite observations in the second half of the 20th century was combined with Quantum Mechanics developed in the first half of the 20th century that a real understanding was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



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.

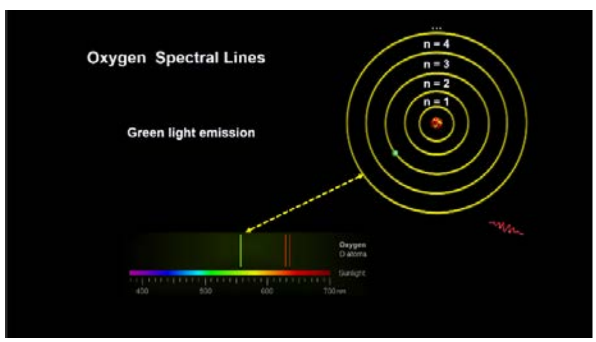
Quantum Mechanics explains how these collisions create light. I'll take a minute to explain this because it's relevant for understanding how a star's light can tell us how far away the star is.

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.



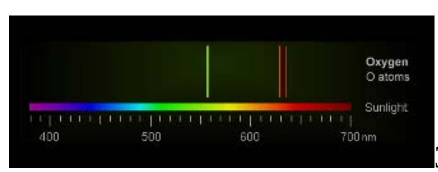
And, thanks to Albert Einstein, we discovered that light was quantized as photons and that they were:

- 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.



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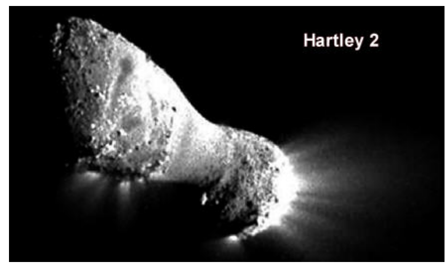
We'll go deeper into quantum mechanics and light at the beginning of our segment on distant stars

[Music @11:51 - *Williams, Vaugan: Fantasia on a Theme by Thomas Tallis; Royal Philharmonic Orchestra; from the album "Britten/Vaughan Williams/Tippett", 1990*]

Comets

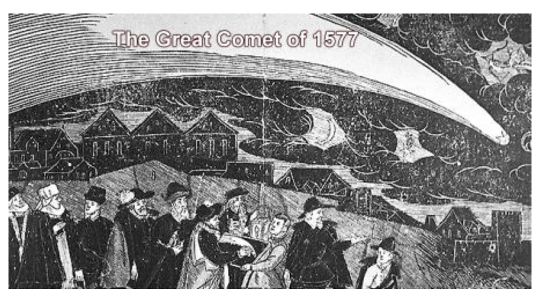
A comet is a small Solar System object made of a mixture of frozen water, ammonia and various hydrocarbons, such as methane. When passing close to the Sun, it heats up and begins to outgas and displaying a visible atmosphere or coma, and sometimes a tail – the coma pushed back by the solar wind. You can see the jets in this close up photo of comet Hartley 2.



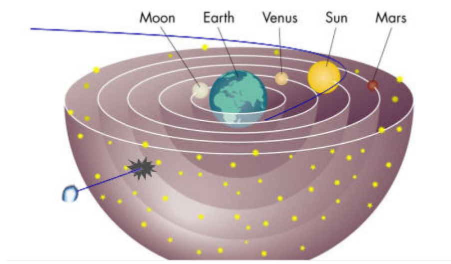
Comet nuclei range from a few hundred meters to tens of kilometers across. The coma and tail are much larger and, if sufficiently bright, may be seen from Earth without a telescope, like this image of Comet ISON.

From ancient Greece to the middle of the 16th century, Comets were thought to be luminous vapors in the earth's atmosphere. Here's a tapestry that illustrates the 1066 comet.

Here's the Great Comet of 1577 as seen over Prague. Tyco Brahe studied this very bright comet that shone in the night sky for 74 days. He found that he could not see any parallax. From his data, he concluded that the comet must be at least six times further away from the Earth than the Moon. This took it out of the earth's atmosphere and started people thinking differently about comets and planets.

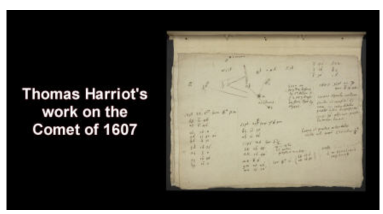


Remember that the Ptolemy model had rotating spheres holding each plant in place. Tyco's finding would have comets crashing through these crystal spheres. As you can imagine, this tipped the scales in favor of the Copernican sun centric model and left open the question about just what holds the comets up.



Using the Great Comet of 1680, Edmund Halley worked with Isaac Newton to find out if comets were subject to the same forces as Newton had proposed for the planets. The data showed that the long elliptical paths of the comets fit Newton's theory of gravity perfectly.

In 1705 Halley studied the recorded paths for the comets of 1531, 1607, and 1682. He proposed that they were all re-appearances of the same comet and that it would be back again in 1758. It was. This was a spectacular vindication of his bold conjecture and of Newton's gravitational theory. For his success, the comet was named after him – Halley's Comet.



I saw it in 1986. Its orbit goes out past Pluto, so it won't be back again until 2061.


COMING END OF WORLD

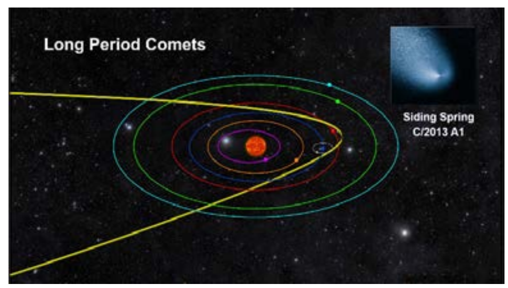
Halley's Comet May Snuff Out Life on the Earth

Here we see the 1910 Halley's Comet. **[Note:** The Earth actually passed through its tail. By 1910, spectroscopy was able to detect the elements in the tails of comets. This produced quite a scare when Haley's comet's tail was found to contain the toxic gas cyanogen.**]**

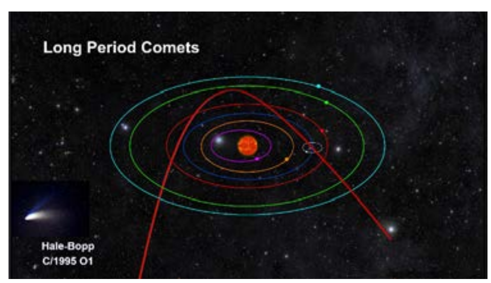
Comet Orbits

Comets come at us from all directions. And we have seen that they have two kinds of orbits: long and short. Long period comets can take thousands of years and have unpredictable orbits. Here are a few of them.

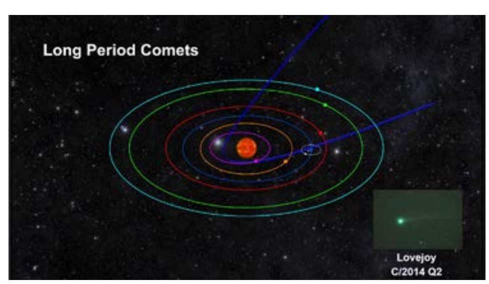
Siding Spring visited us in 2013-2014 and came very close to Mars. Mars orbiters at the time detected hundreds of kilograms per hour of the comet's dust [composed of magnesium, iron, sodium, potassium, manganese, nickel, chromium and zinc]. It won't be back for millions of years.



Hale-Bopp was one of the brightest comets in decades. It was visible to the naked eye for 18 months. That was twice as long as the previous record held by the Great Comet of 1811. Hale-Bopp is expected back in the year 4385.

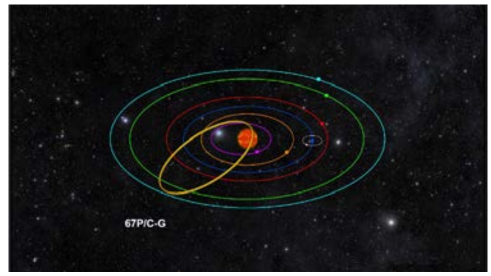


Lovejoy 2014 approached Earth to within half our distance from the Sun. It had travelled inbound for 11 thousand years. It won't return for almost 20 thousand more years.

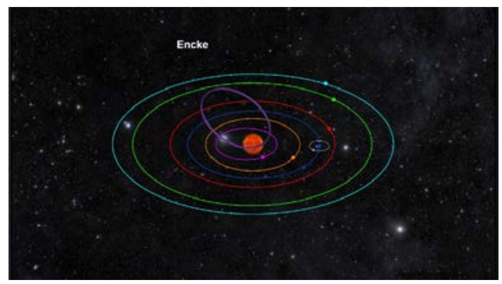


Short period comets (aka periodic comets) take as few as 3 and as long as 200 years. They are also much more predictable.

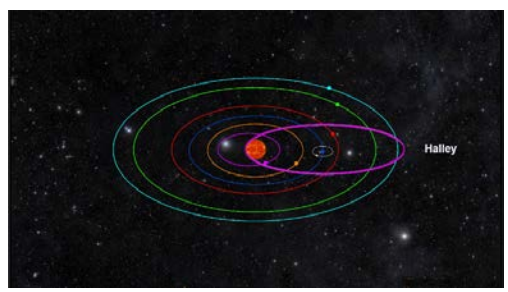
67P has an orbital period of just under 6 and a half years. At the end of this segment, we'll be covering the Rosetta Mission that landed a probe on this comet in 2014.



Encke orbits the sun in just 3.3 years. It is thought to be the originator of several meteor showers here on Earth.



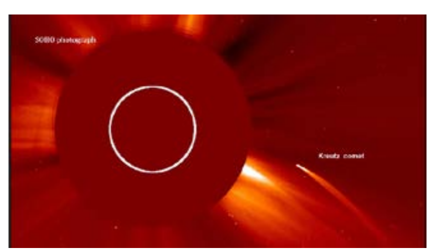
And we have already discussed Halley's Comet. My grandchildren will see it in 2061.



The fact that there are two kinds of orbits (long and short) lead to the idea that comets originate from two different places - with the short period comets coming from the Kuiper Belt and the longer period comets coming from a proposed area called the Oort Cloud.

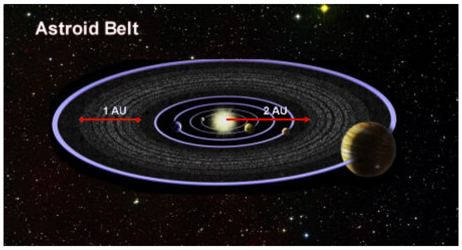
Kuiper Belt

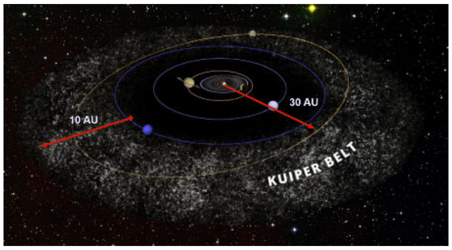
Short period comets visit the Sun so often that they quickly evaporate -- vanishing in only a few hundred thousand years. Here's one that evaporated in the Sun's corona in July 2011. It was traveling at 644 km/s (that's 400 miles/s).



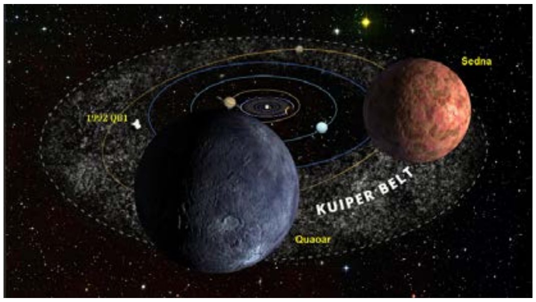
Here we see it in time lapse from the Solar Dynamics Observatory. The comet enters on the right in this video. In this second pass, I've marked it along the way. It starts out with the mass of an aircraft carrier and it's completely evaporated in 20 minutes by the searing heat of the Sun's corona.

They evaporate so quickly, compared to the age of the solar system, that we shouldn't see any left at all. Yet we routinely track dozens of them every year. In 1951, Gerard Kuiper proposed that there must be a belt of icy bodies orbiting beyond Neptune that is a source for new comets. It is much further away, much larger and far less dense than the Asteroid Belt. It starts at 30 AU from the sun and is 20 AU wide.



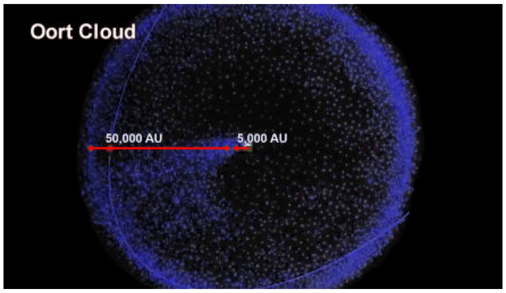


1992QB1 was the first Kuiper Belt Object (KBO for short) found. In 2002, a large KBO hundreds of kilometers in diameter named Quaoar was found. [This object was photographed in 1980, but was not noticed in those images.] In 2004, KBO Sedna (2003VB12) was discovered. And we have seen that Pluto and Makemake are dwarf planet KBOs. It is estimated that the Kuiper Belt contains a 100 million comets.



Oort Cloud

In 1950, in order to explain long period orbits, the Dutch astronomer Jan Oort proposed the existence of a cloud of comets between 5,000 and 55,000 astronomical units from the sun.



Other estimates have it going out much further. All estimates put the Oort cloud well outside the Heliosphere. Oort estimated that this reservoir contained 100 billion comets. Siding Spring, Hale-Bopp, and Lovejoy 2014 are three of them.

No space probe has yet been sent to the area of the Oort cloud. Voyager 1, in the Heliosheath is traveling at 1.6 million km per day (that's a million miles per day). It will take over 1,200 years just to reach the Oort Cloud, and over 12 thousand years to pass through it. So its existence will remain a theory for some time to come.

Shoemaker Levy

We'll end our segment on comets with a look at two of them that changed our thinking and our capabilities when it comes to these objects.

In 1994, the comet Shoemaker Levy collided with Jupiter.

The first impact occurred at 20:13 on July 16, when fragment A of the nucleus entered Jupiter's southern hemisphere at a speed of about 60 km/s (that's 37 miles per second). Instruments on the nearby Galileo spacecraft detected a fireball plume that reached a height of almost 3,200 km. (that's 2,000 miles.) Remember that our atmosphere extends only a few hundred km above us.

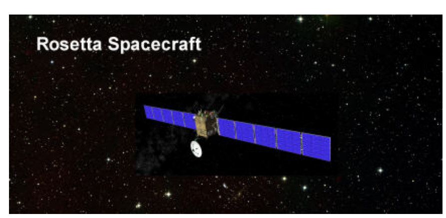
Observers soon saw a huge dark spot after the first impact – 6,000 km wide (3,700 miles). Over the next 6 days, 21 distinct impacts were observed, with the largest coming on July 18. This impact created a giant dark spot larger than the Earth. Jupiter absorbed them all. The changes to the planet were dramatic but disappeared after a few months. But if Shoemaker Levy had hit the Earth instead of Jupiter, It would have wiped us out.

This highlighted for everyone the importance of understanding comets (and asteroids) and how to change their trajectory should we ever find one heading our way. Progress in this area has been made.

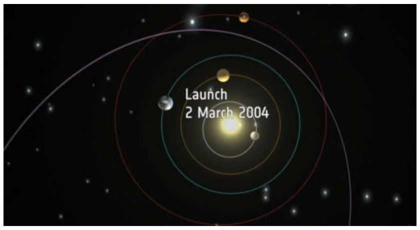
Rosetta Mission to Comet 67P/Churyumov-Gerasimenko

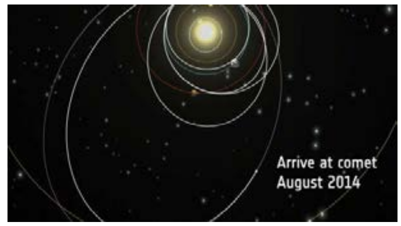
Here's a close up look at comet 67P/CG. Its overall length is 5 km. And the larger of its two lobes is 4.1 km wide. That might not sound like much, but here' what an object this size would look like if we placed it over a city like Toronto, Canada.

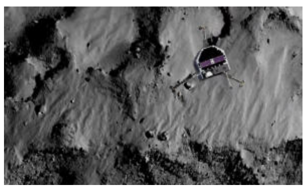
The European Space Agency launched the spacecraft Rosetta in 2004. Its mission was to rendezvous with comet 67P; deploy a lander called Philae to its surface; and escort the comet as it orbits the Sun.



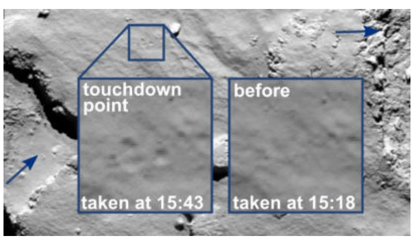
Ten years later, on August 6th, 2014, after getting several gravity assisted velocity busts, and traveling 6.4 billion kilometer, *Rosetta* rendezvoused with 67P.



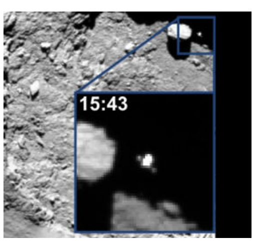




Philae landed on the surface on November 12th, becoming the first spacecraft to land on a comet. Here we see the lander's big bounce off the comet with these pictures captured by

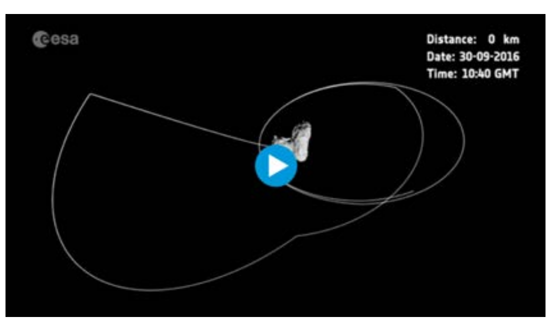


its orbiting mother ship. This is where it first landed. You can see the before and after pictures where Philae made its mark. But the harpoons that were meant to anchor it to the comet did not deploy.

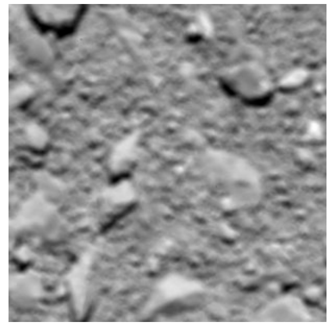


It ended in the shade and has lost its power. But Rosetta continued to transmit for another two years before its power ran out as well.

At that point, in September 2016, the Rosetta mission concluded with a controlled impact onto the comet. Here's the collision course into the comet from an altitude of around 19 km.

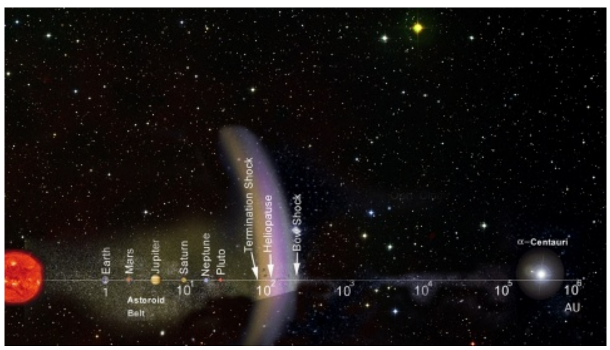


Rosetta targeted a region on the small lobe of the comet, close to a region of active pits. Pits are of particular interest because they play an important role in a comet's activity. Transmissions continued up to the moment of impact. The comet is now beyond the orbit of Jupiter and heading for the Kuiper Belt. It will return with Rosetta's wreckage on board in 2021.



Solar System Review

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



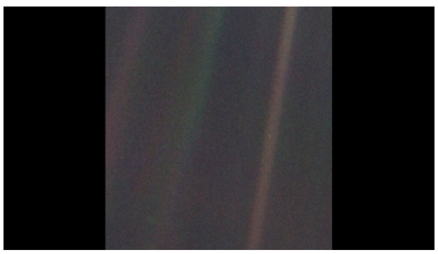
- The Sun is 150 million km (93 million miles) away and a millions earths could fit inside it.
- Mars' orbit is half again as far away as that at 78 million km (48 million miles) from ours.
- Jupiter, the largest planet in the Solar System is 5.2 times further away from the sun than the Earth is. That puts its orbit 772 million km (480 million miles) away from ours.
- The Asteroid Belt fits between Mars' and Jupiter's orbit.
- Pluto's orbit in the Kuiper Belt is 5.6 billion km (3 and a half billion miles) away.
- We have seen that the Kuiper Belt goes from 4 and a half billion km (2.8 billion miles) out to 7 and a half billion km (4.3 billion miles).
- The Termination Shock is 18 billion km (11 Billion miles) away.
- And the Bow Shock is thought to be 19 billion km (12 billion miles) away.
- We have just seen that the Oort Cloud starts much further away than that at 748 billion km (465 billon miles) and extends out to 8.2 trillion km (5.1 trillion miles) or more.

We have used direct measurement by going there, triangulation, and planetary parallax to calculate these Solar System Distances. In our next segment on Nearby Stars, we'll advance our cosmic distance ladder to cover how we know how far away it is to Proxima Centauri, our nearest stellar neighbor.

[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*]