

Lookback Time in Our Everyday Lives

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One of the activities that we have done as part of the GSUSA Astronomy Camps is *Lookback Time*. The farther away we look out into the Universe, the farther back in time that we see. Why is this? Do we ever experience this effect in our everyday lives?

Lookback all comes down to the speed of light, 299,792 kilometers per second (186,282 miles per second or 670,615,000 miles per hour). If you could travel at the speed of light, you could circle the Earth 7.5 times in one second (though light travels in a straight line)!

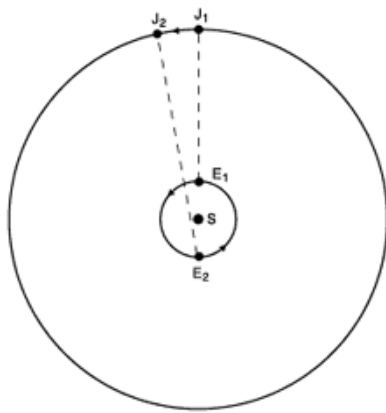
In a way, we see and hear lookback time all of the time. When we are watching fireworks, we see the magnificent display before we hear the loud bang that it makes. When there is a thunderstorm, we see the lightning and then, a few seconds later, we hear the thunder. That is because sound travels at “only” 1,235 kilometers per hour (343 meters per second, 767 miles per hour, 1,125 feet per second). So, if a lightning strike is a mile away, we see it almost the instant it happened (0.000005 seconds later), but do not hear it for more than four seconds.

However, we also see the effects of the speed of light in our everyday lives. When you watch the news, you see the person in the studio asking a reporter in another city a question. There is a delay in the reporter’s response. Why? Actually there are two reasons: electronic and distance. First, video signals are electronically compressed and digitized. This can add about a second to the time it takes us to see the reporter. The second factor is distance. The person in the studio asks the reporter a question and then the signal is sent to a geosynchronous satellite that is orbiting 35,800 km (22,200 miles) above the Earth’s equator. These satellites orbit the Earth in 24 hours so they stay above the same place on Earth—antennas on Earth can always point at them without moving. The signal then goes to the reporter in the field. The reporter then responds, with the response going back up to the satellite before being transmitted back to the studio. The total distance is at least 143,000 kilometers (more if the signal has to go through more than one satellite) which takes a total of about 0.5 seconds. For you at home, all of this is history since it takes more than a second for the story to go from the studio to you via another satellite link. From the time the person asks a question in the studio until you actually see the reporter answer the question is probably three seconds or more; “old” news!

As a side note, when we talk about “the speed of light,” we are talking about how fast all electromagnetic radiation travels; light and radio waves are both part of the electromagnetic spectrum.

Background: the speed of light—caution, there is math involved!

The concept of light having a finite speed dates back to about the time of Aristotle. However, it was not until the early part of the 1600s that Galileo and others proposed experiments to determine its speed. Some of these experiments were tried, but they failed to determine a speed of light since the distances used were too small (a few miles). It was not until 1676 that an actual measurement of the speed of light was made. Giovanni Cassini and his staff had been making observations of the moons of Jupiter. They used these observations to determine the orbital period of Io (Jupiter’s inner moon) by observing Io as it came out of Jupiter’s shadow—a lunar eclipse. However, as the Earth in its orbit moved away from Jupiter in its orbit, Io’s emergence from the shadow occurred later and later than he had predicted. One of



**Orbits
of Jupiter
and Earth**

Cassini’s staff, Ole Rømer, realized that this was due to the additional time it took for the light to get to the Earth from Jupiter and Io. Rømer estimated that it took 22 minutes more for the light from Io and Jupiter to reach us when we were on the “far side” of the Sun. Rømer’s observations were used to estimate that the speed of light was about 225,000 kilometers per second (140,000 miles per second), about 30% less than the currently accepted value.

Ultimately, it took Earth-based and laboratory-based measurements to determine the now-accepted value of 299,792.458 kilometers per second in a vacuum (and about 0.03% slower in the Earth’s atmosphere), accurate to 1 meter per second.

If you think about it, there are three interrelated units: c , the speed of light; m , the meter; and s , the second ($c = \lambda/f$, where λ is the wavelength in meters and f is frequency in cycles per second). In 1983, the *definition* of the meter was fixed to be the distance light, in a vacuum, travels in $1/299792458$ seconds. More accurate methods in the laboratory are then be used to measure the length of the meter and the duration of a second. The meter is now known to an accuracy of about 2.5 parts in 10^{11} using a helium-neon laser and the duration of a second has an accuracy of about five parts in 10^{16} using a cesium atomic clock.

Communicating with spacecraft

When astronauts went to the Moon, they were about 384,400 kilometers (239,000 miles) away. Therefore, when Neil Armstrong spoke his famous words, “The Eagle has landed,” and later “One small step...,” it took 1.3 seconds for those words to get from the Moon to the Earth.

Below is a table of the mean distances of the planets from the Sun in astronomical units (1 AU = the mean distance of the Earth from the Sun, 149.6 million kilometers) and in light time from the planet to the Sun.

Therefore, when the Mars Rovers, Spirit and Opportunity, and the Mars Phoenix lander send pictures back to Earth, it can take from a little over 4 minutes (when Mars and Earth are on the same side of the Sun) up to more than 20 minutes (when Mars is on the other side of the Sun).

Voyager 1 is now over 100 AU from the Earth, so when it sends back its information to us, by the time the signal gets to us, it is telling us what was observed about 14 hours earlier.

Planet	Distance		Planet	Distance	
	AU	Light time		AU	Light time
Mercury	0.39	3.2 min	Venus	0.72	6.0 min
Earth	1.00	8.3 min	Mars	1.52	12.6 min
Jupiter	5.20	43.2 min	Saturn	9.54	79.2 min
Uranus	19.2	2.6 hr	Neptune	30.1	4.2 hr
Pluto	39.5	5.5 hr	Oort Cloud (comets)	2,000 to 50,000	280 days to 7000 days

Stellar distances and the 3D nature of the heavens

We use the Astronomical Unit as our unit of length for measuring distances in the Solar System. However, because stellar distances are so large, astronomers use another unit of length, the light-year (ly). The light-year is defined as the **distance** light travels in one year, 9.46 trillion kilometers (5.88 trillion miles or 63,241 AU). Next to the Sun, the closest star to the Earth is Proxima Centauri at 39.9 trillion kilometers (24.8 trillion miles, 267,000 AU, 4.22 ly). Therefore, it takes light 4.2 years to get to us. If something happened to Proxima Centauri, we would not know it for 4.2 years! For us in the northern hemisphere, the closest star that we can see in our sky is Sirius (the brightest star in the sky after the Sun) at 8.5 light-years.

When we look at the star patterns in the sky that we call asterisms (the simple patterns like the Big Dipper and the Summer Triangle) and constellations (like Ursa Major, the Great Bear), what we are seeing is a group of bright stars that happen to be in the same direction as seen from our perspective on Earth. In actuality, the stars can be at vastly different distances. We have an activity called *3D Constellations* that demonstrates this for several constellations. We also have a related activity called *The Earth in Motion*.

Measuring distances—more math

How do we measure distances in space? If you hold your index finger at arm's length and blink your eyes (one at a time), your finger will *appear* to move back and forth relative to a more distant object. Each eye sees your finger at a slightly different angle. This is parallax, the same principle that allows us to use our eyes to estimate distances (and one of the reasons we have two eyes) or to watch 3D movies. Surveyors use this method to determine distances on Earth. Looking at an object from slightly different positions (much as blinking our eyes gives us different angles), they can measure the distance to a more distant object. Scientists can use parallax to measure distances, too. By looking at the Moon from different places on the Earth, early astronomers were able to measure the distance to the Moon. Later astronomers used the parallax of the Sun, relative to the diameter of the Earth, to determine the distance to the Sun, the Astronomical Unit, and gave us the scale of the Solar System. Taking this to the next step, if you look at “nearby” stars from opposite ends of Earth's orbit, you will see that they appear to move back and forth, similar to your finger and blinking your eyes! The distances to over 7,000 stars out to about 500 light years are known to an accuracy of better than 5%. Beyond this, distances are likely to be much less accurate, 10% or less. These distances can be done by parallax (up to about 1000 light years), estimating the distance by how bright a star appears to be (further away, looks fainter), or, in the case of expanding supernova remnants (nebula), measuring (or estimating) the speed at which the remnant is expanding and making diameter measurements several years apart (further away, looks smaller). Uncertainties for these may be 20% or more!

Lucy, phone home

AM radio signals are refracted by the atmosphere and reflected by the ionosphere, so the first commercial radio signals that could be detected beyond the Earth's atmosphere were TV signals. Hence, science fiction movies and TV shows have used TV broadcasts as our first “contact” with beings from other worlds—they were “watching” us through our TV broadcasts. Two examples of this are the movie *Contact* where the first signals we receive from space are a rebroadcast of Hitler at the 1936 Summer Olympics in Germany while an episode of *Amazing Stories*, *Fine Tuning* has a boy tuning in on the broadcasts of aliens who are getting ready to visit Earth. They have created their own versions of *I Love Lucy*, the *George Burns and Gracie Allen Show*, and other early 50s sitcoms and now want to come to Earth to meet their favorite TV stars!

So how long would it really take for aliens in another star system to receive our TV shows? The real boom in TV occurred just about 60 years ago. So, civilizations as far away as 60 light-years are regularly getting our TV programs (not even in reruns yet), and civilizations within 30 light-years have been able to receive our broadcasts and send back hellos.

As of the writing of this activity (March 2013), there were 861 confirmed extrasolar planets (exoplanets) orbiting more than 677 stars (128 of these with multiple planets). Of these, more than 20 Earth-like exoplanets are within 50 light-years of Earth.




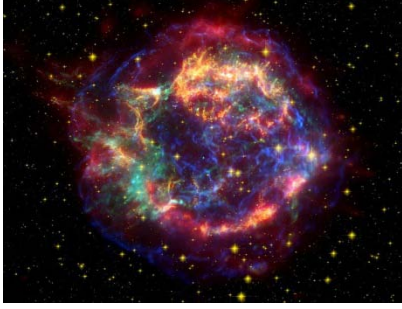
Astronomical events

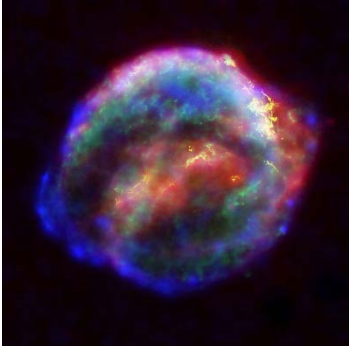
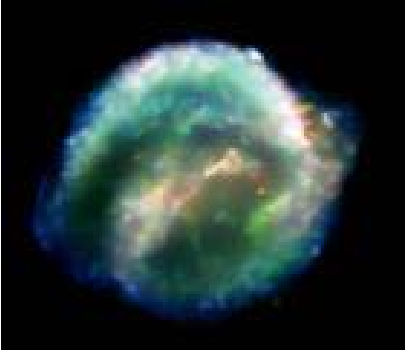
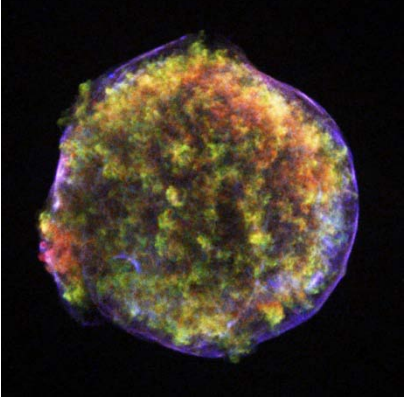
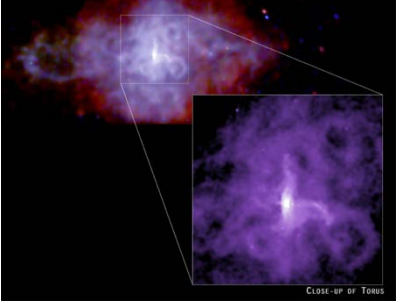
Novas and supernovas are astronomical events that have been recorded down through history. The remnants of some of these are now seen as glowing nebulae. Below is a list of some of these events, when they were seen on Earth, and when they actually occurred (taking into account the light time to get from there to here). The misconception of when these events occurred came up recently when a spacecraft discovered the remnants of a supernova that occurred near the center of our galaxy. Most of the news releases stated that the event occurred only about 140 years ago. In reality, it could have been seen here on Earth 140 years ago, but it actually occurred about $26,000 \pm 1,400$ years ago, the distance to the center of our galaxy. Please note that, in the table below, my math is not that bad. Distances to nebulae are only approximations. They are usually determined by estimating the speed at which they are expanding and their true sizes. Therefore, the distances to these nebulae are sometimes uncertain by hundreds or even thousands of light-years (ly).


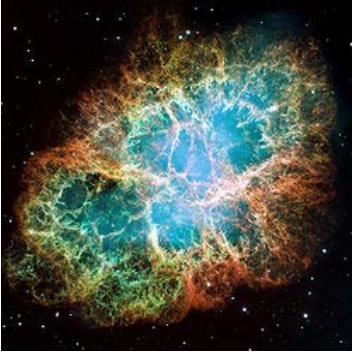



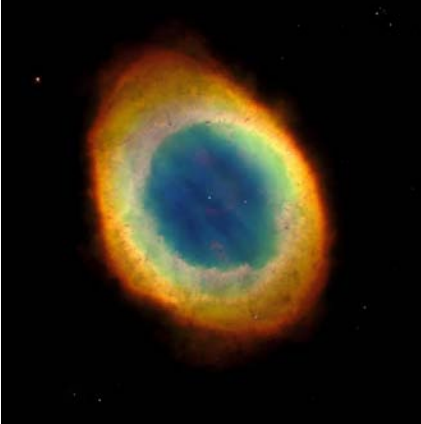

Lookback time


What does this mean? When we “see” an event, such as a supernova explosion, we are actually seeing something that happened thousands of years ago. The event is now thousands of years old. One way of viewing these events is to say which event occurred first. There were three supernovas seen by observers on Earth in a period of about 100 years: Tycho in 1572, Kepler in 1604, and Flamsteed in 1680. Even though these astronomers saw these supernovas over a period of 100 years, these supernovas actually occurred over a period of about 7,000 years with the supernova that Kepler saw being the first event. For stars that have “lifetimes” of billions of years, a few thousand years has little meaning. However, if we now think about nearby and distant galaxies, we can view lookback in a different way. Let us assume that the Milky Way Galaxy, our galaxy, and the Andromeda Galaxy, our nearest neighbor at a distance of 2.5 million light-years, are the same age. Since it takes light 2.5 million years to get here, we are seeing the Andromeda Galaxy when it was 2.5 million years younger. When NIRCam (Near Infrared Camera) and JWST (James Webb Telescope) look back at distant galaxies that are, say, 13 billion light-years away, we are seeing them as they looked 13 billion years ago when they were much younger and perhaps we will be seeing them as they first formed into the galaxies we see today.

Year	Supernova Name/Observed	Remnant Name (Nebula)	Distance (ly) Uncertainty may be 20% or more	How Long Ago It Happened (Years)
1987	SN 1987A Discovered (independently): Chile, New Zealand, Zimbabwe; naked eye object	SNR 1987A	~168,000	~168,000
~1868	No record	G1.9+3.9	~26,000	~26,000
1680	Seen by: John Flamsteed?	Cassiopeia A	~11,000	~11,000
1604	SN 1604, Kepler's Supernova Seen by: Johannes Kepler	Kepler's Supernova Remnant (SNR)	~15,000	~15,000
1572	SN 1572, Tycho's Supernova Seen by: Tycho Brahe	Tycho's SNR	~7,500	~8,000
1181	SN 1181 Recorded in: China, Japan	3C58	~10,000	~11,000
1054	SN 1054 Recorded in: China, Japan, North America (Anasazi;Chaco Canyon)	Crab Nebula	~6,500	~7,500
1006	SN 1006 Recorded in: Switzerland, Egypt, Iraq, China, Japan, North America (Hohokam)?	SNR 1006	~7,200	~8,200
~400	No record	Ring Nebula	~2,300	~4,000
386	SN 386 Recorded in: China	G011.2-00.3	~1,500	~3,000
185	SN 185 Recorded in: China	RCW 86	~3,300	~5,100

Supernova Remnant	Image, visible	Image, other
SNR 1987A	 <p data-bbox="483 693 646 730">HST (Insert)</p>	
G1.9+3.9		 <p data-bbox="945 1171 1156 1209">Chandra (X-ray)</p>
Cas A	 <p data-bbox="483 1579 548 1617">HST</p>	 <p data-bbox="945 1579 1302 1617">HST, Spitzer (IR), Chandra</p>

Kepler's SNR	 <p data-bbox="479 514 657 556">HST, Spitzer</p>	 <p data-bbox="941 514 1055 556">Chandra</p>
Tycho's SNR		 <p data-bbox="941 1018 1055 1060">Chandra</p>
3C58		 <p data-bbox="941 1428 1055 1470">Chandra</p>

<p>Crab Nebula</p> 	 <p>HST</p>	 <p>Spitzer</p>
<p>SN 1006</p>	 <p>HST</p>	 <p>Chandra</p>
<p>Ring Nebula</p>	 <p>HST</p>	 <p>Spitzer</p>

SN 386		 <p data-bbox="943 569 1057 604">Chandra</p>
SN 185		 <p data-bbox="943 1024 1360 1060">Chandra, Xmm-Newton (X-ray)</p>