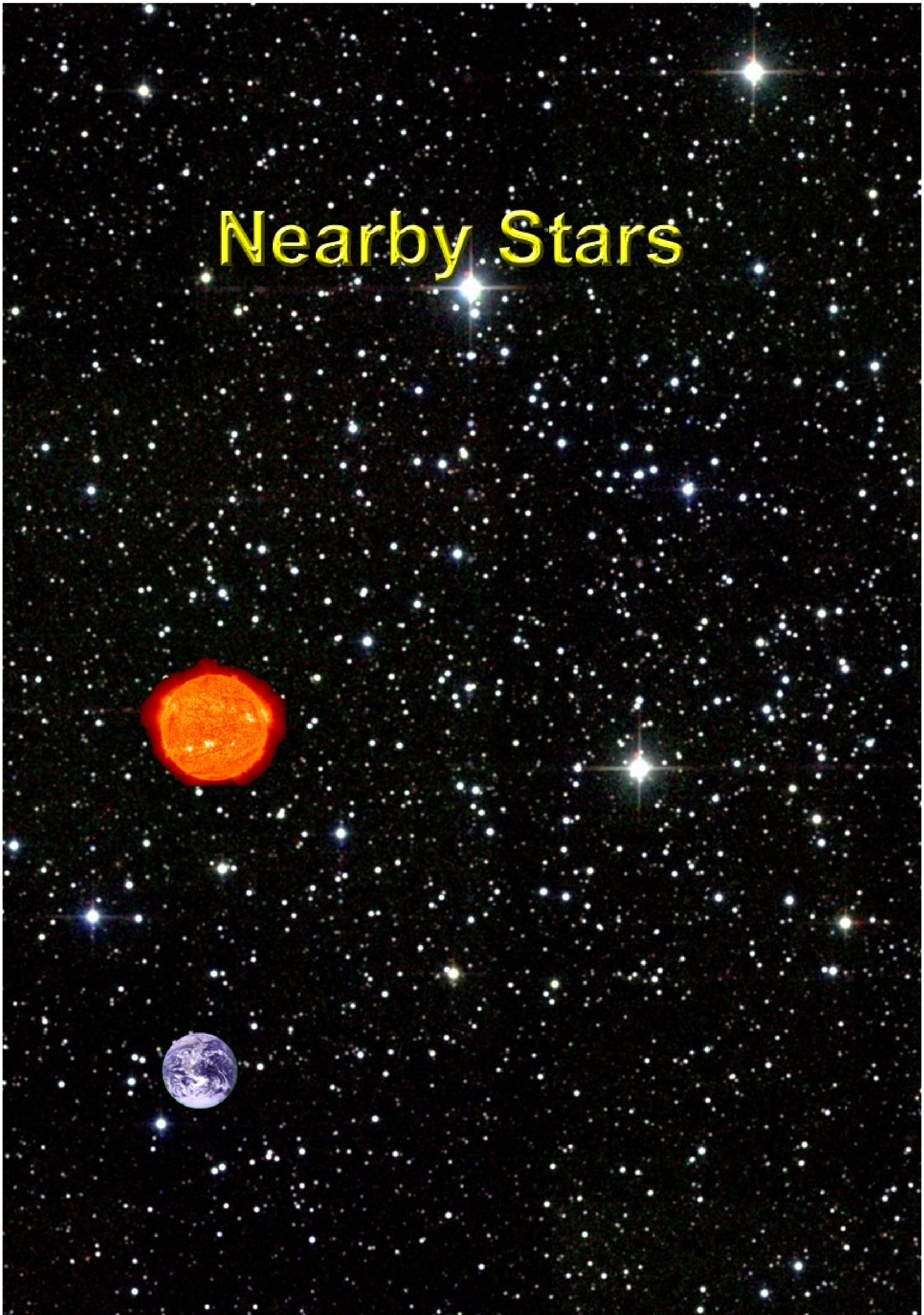

Nearby Stars

Nearby Stars

*{**Abstract** – In this segment of our video book, we take a look at our stellar neighborhood and how we know how far away these nearby stars are.*

We cover the first stellar parallax measurement form the star Cygni 61. Then we examine our stellar neighborhood including: Proxima Centauri, Alpha Centauri, Barnard's Star with its Proper Motion, Wolf 359, Lalande 21185, Sirius A & B, 61 Cygni, Altair, Fomalhaut with its planet, and Vega.

A deeper look into what we mean by 'luminosity' is outlined. We point out that it is measured in watts just like a light bulb and that its value over distance from a point source follows the 'inverse square law'. We use our Sun as an example and introduce Einstein's famous "energy = mass time the speed of light squared" formula.

We then cover some more stars including: Pollux, Arcturus, GJ1214, Capella, and Castor. Having reached the limits of ground based telescopes to measure parallax, we discuss the European Space Agency's Hipparcos satellite and the more distant stars it helped fined parallax for including: HD 189733, Aldebaran, Mizar, Spica, Mira, Polaris, and Antares. Along the way, we cover how a star's mass is calculated from the motion of binary stars, and then we build the mass vs. luminosity empirical graph.

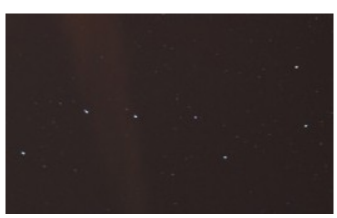
*We end by pointing out that parallax only takes us to a small percentage of stars in the Milky Way and that we'll need to know more about light to go any further.**}***

Introduction

Twinkle twinkle little star. I imagine that hundreds of thousands of generations have wondered what they are.

> ***[Music:** "Twinkle twinkle little star": This children's music asks the ancient question "what are stars?" This is the very question we will attempt to answer in this video book segment.**]***

Here I am again in my back yard, looking at the Big Dipper. On a clear dark night, I can see around a thousand stars. For the longest time, it was not known whether stars like these shined by their own light,



or whether they were reflecting the Sun's light, as all the planets, moons, comets, and asteroids do. It's only in the last couple of generations that we have finally reached a point where we know what stars are.

You'll recall that Copernicus first proposed a Sun centric model for the solar system. But you'll note that the outermost celestial sphere did not go away with the Copernican model.

Parallax measurements showed us that the Sun was at the center of our planetary system. But no one could find any parallax in the stars – not Tycho Brahe, not Kepler, not Galileo, not even Newton.

<u>First Stellar Parallax</u>

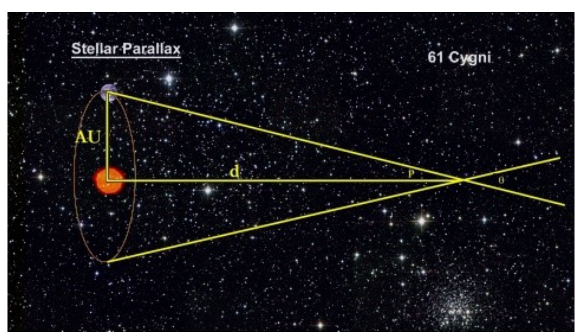
The reason it took so long is that stars are so far away, that parallax angles are just too small for the available instruments. Remember that the moon's parallax was ½ of a degree. But star parallax is measured in fractions of an arch second. **[**That's why it took over 300 years of trial and error after Copernicus, before it became possible to measure these small angles.**]**

> **[Music:** *Carl maria von Weber's "Der Freischütz - Ouvertüre": Taking aim at the stars with telescopes in place of bullets, this overture to the Der Freischütz opera written in 1821 makes for a great start for our first steps towards the heavens.***]**

In the 1830s, there was a race to see who could find the first real stellar parallax. The astronomer Fredrich Bessel won. The star was 61 Cygni.

Here's how it works. If you recall, the maximum baseline for parallax measurement for planets was the diameter of the Earth. For stellar parallax, we have the diameter of the Earth's orbit around the Sun. That's an increase from around 8 thousand miles to 186 million miles. **[**That's 23 thousand times larger.**]**

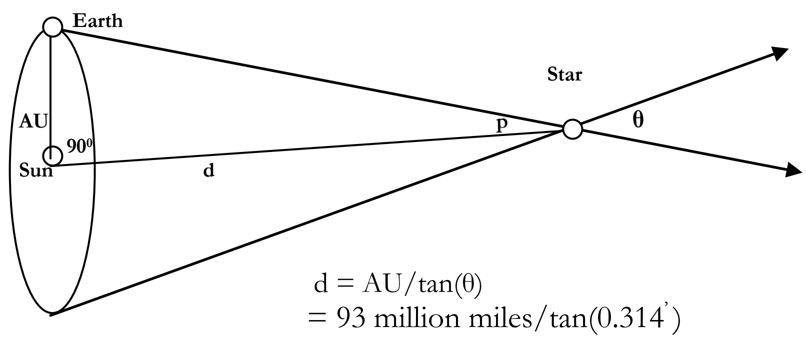
So from one side of the earth's orbit (say in July) we take a line to the star, and map the positions of the more distant stars. Six months later in January, we repeat the process. This gives us the angle θ. We define stellar parallax as ½ this angle. This would be the angle at the star with the Earth and the Sun marking the other two corners of a right triangle. The math is the same trigonometry we used for finding distances to the rock in my back yard and to the planets in our solar system.



Of course this is an oversimplification. Fredrich Bessel mapped 61 Cygni against the distant star background for 28 years observing the star's ellipse that followed the earth's orbit. In 1838, after thousands of measurements and calculations, he made scientific headlines by announcing that the parallax of 61 Cygni was 0.314 arcseconds. That gives us a distance of 61 trillion miles. That's over 6 million times further from the sun than we are. Why too far to be reflecting the Sun's light. So, at this point, in the middle of the 19th century, we knew that stars burned with their own light.

Stellar Parallax

Parallax = P = ½ θ
Baseline = AU = 93 million miles



$d = AU/\tan(\theta)$
$= 93$ million miles$/\tan(0.314')$
$= 61{,}100{,}000$ million miles
$= 10.4$ light years

You may have heard the term ‘parsec’. Astronomers like to use it for measuring distances to stars. Using the method described here, a parsec is the distance an object would be if its parallax was 1 arc second. It gets its name from the first syllable of ‘parallax’ and the first syllable of ‘second’. It computes to 19.2 trillion miles.

As we discussed in our segment on the Solar System, light travels at 186,000 miles a second. To calculate how far it goes in a year, we multiply this number by the seconds in a minute; minutes in an hour; hours in a day; and days in a year. That totals 5.86 trillion miles per year. We call that 1 light year. So 1 parsec is equal to 3.262 light years. I’ll use light years throughout this video book, but parsecs will come up from time to time. Also, if you’re a Star Trek fan, you’ll hear parsecs used a lot in their distance calculations.

Stellar neighborhood

Let’s take a look at some of the stars in our neighborhood - out to around 25 light years. That’s about as far as stellar parallax measurements from ground based telescopes can take us.

Proxima Centauri - 4.22 light-years

Proxima Centauri is a dim red star. It is the nearest known star to the Sun.

Alpha Centauri – 4.36 light-years

Alpha Centauri A and B form a close binary system that is separated "on average" by a distance slightly greater than the distance between Uranus and the Sun. A, the main star, is bright and yellowish. B is not quite as bright and has an orange tinge.

> **[Additional info:** Proxima Centauri is very close to these two stars and may be part of what would then be a triple star system.**]**

Barnard’s Star - 5.94 light years

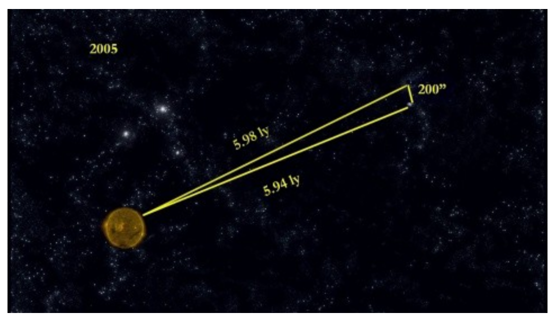
Barnard's Star is a dim red star. It’s called a “runaway” star because it’s approaching the Sun so rapidly that around 11,700 AD, it will be 3.8 light years from the Sun - and that will make **it** the closest star to our own!

Proper Motion

This motion across the sky is called Proper Motion. This rapid motion is easily identified using parallax techniques.

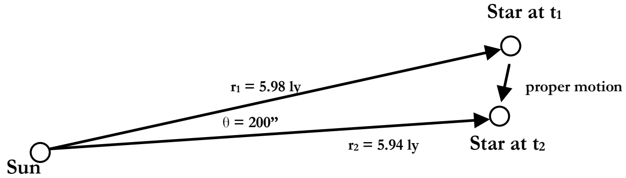
> **[Additional info:** For the most part, the position of stars is virtually identical from century to century and yet, a very small number of these stars show dramatic motion across the sky when observed from year to year.**]**

Here’s a look at Barnard’s Star photographed in 1985. Its parallax measurement indicates that its distance is 5.98 light years. In this second photograph, taken 20 years later in 2005, we see that the star has moved 200 arc seconds, and its new distance is 5.94 light years. That’s 10” of arch across the sky per year.



Proper Motion

Average distance = r = 5.96 light years



Proper Motion = r_{avg} x tan(θ) = 5.96ly x tan(10”)
= .000288 ly = 1.7 billion miles/yr
= 201,000 miles/hr

Radial Motion = $(r_1 – r_2)$ly/20 years = .002 ly/yr
= 11.7 billion miles/yr
= 1.33 million miles/hr

Wolf 359 - 7.78 light years

Getting back to nearby stars, here's Wolf 359. It is another dim red star. In fact, it's one of the least luminous stars known.

Star Trek fans may recognize Wolf 359 as the scene of a great battle between the Federation and The Borg.

Lalande 21185 - 8.32 light years

Lalande 21185 is another dime red star. Recent analysis indicates that it may also be accompanied by at least two orbiting planets, but his has not been confirmed. Planet hunting is a hot topic these days and research is ongoing.

Sirius A & B - 8.6 light-years

This Hubble Space Telescope image shows a white Sirius A, the brightest star in our nighttime sky, along with its faint, white tiny stellar companion, Sirius B. The two stars revolve around each other every 50 years.

> **[Additional info:** Astronomers overexposed the image of Sirius A so that the dim Sirius B [tiny dot at lower left] could be seen.**]**

61-Cygni – 11.4 light years

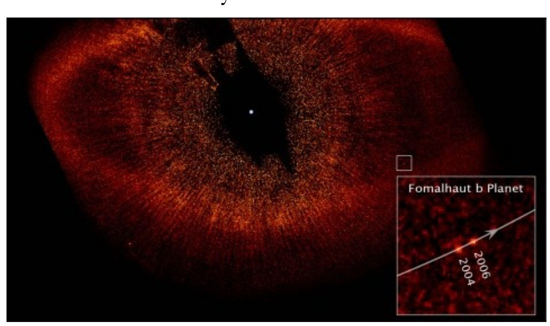
Here we have our first parallax star, 61 Cygni again. It has another claim to fame in that it was first noted to have a high proper motion as early as 1792, when it got the nickname "Flying Star". To add further to its uniqueness, in 1830 61-Cygni was determined to be a binary star system with two orange stars.

Altair 16.7 - light-years

Altair is a bright white star. A recent study revealed that Altair is not spherical, but is flattened at the poles due to a very high rate of rotation.

Fomalhaut - 25 light-years

This image of Fomalhaut surrounded by a ring of debris was taken by Hubble.



The white dot in the center of the image marks the star's location. It's a bright white star, but the region around it is black because astronomers used the Advanced Camera's capabilities to block out the star's bright glare so that a dim planet called Fomalhaut b could be seen. The small white box, at the lower right, pinpoints the planet's location.

These observations offer insights into our solar system's formative years, when the planets played a game of demolition derby.

> **[Music:** *Mozart's "Concerto No 10 for 2 pianos & orchestra": Written sometime between 1775 and 1777, this lyrical refrain fits dancing with the stars.***]**

Vega 25 - light-years

Vega is a bright white star and one of the most luminous stars in the Sun's neighborhood. It has been extensively studied. It was the first star to be photographed by astronomers in 1850.

It was the northern pole star around 12,000 BC and will be so again around AD 13,727.

Luminosity

So far, we've identified Wolf 359 as one of the least luminous stars in our neighborhood and Vega as one of the most luminous, but we haven't been explicit as to what we mean by luminous.

Stars have a wide range of apparent brightness as measured here on Earth. The variation in apparent star brightness is caused by two things:

1) Stars have different intrinsic luminosity.

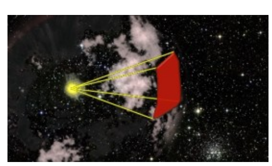
2) Stars are located at different distances from us.

An intrinsically faint, nearby star can appear to be just as bright to us on Earth as an intrinsically luminous, distant star.

Luminosity is what we use to put precise measurements on the idea of brightness. It measures the total amount of electromagnetic energy emitted by a star in watts (just like a light bulb). Apparent brightness is measured in watts/m^2.

> **[Additional info:** For stars, the area we use is the area of the telescope's lens.**]**

Because light from stars spreads out over the surface area of a sphere, we can use the inverse square law to categorize luminosity for all the stars that have parallax distance information.



Take the Sun for example. The apparent brightness of the Sun, as measured in my back yard, is 1400 watts per square meter. If my backyard solar cells where 100% efficient, that's how much electricity each panel would create. Unfortunately, current technology is only 15% efficient, so I'm only getting around 200 Watts per panel.

Plugging our distance to the sun into the inverse square law, we calculate its total luminosity. Here you can see that the answer is a very big number.

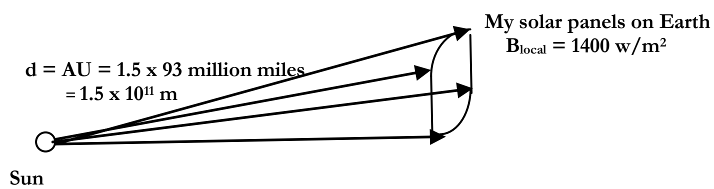
Inverse Square Law

Let B_{local} = Apparent brightness as seen from here on Earth

L_{total} = Total luminosity at the source

Then $B_{local} = L_{total}$ / surface area of a sphere with a radius = d

$= L_{total} / 4\pi d^2$



$L_{total} = B_{local} \times 4\pi d^2$

$= (1400\ w/m^2) \times 4\pi(1.5 \times 10^{11}\ m)^2$

$= 39584 \times 10^{22}$ watts

Using Einstein's famous $E = mc^2$, or Energy = mass time the speed of light squared we calculate that the Sun is fusing 600 million tons/sec of Hydrogen in to Helium, and in the process converting 400 tons/sec of matter into energy.

To put this into perspective, this number is equivalent to around 4 billion Hydrogen bombs exploding per second!

[Additional info: Luckily for us, the Sun has enough mass to keep this process going for another 10 billion years!

The apparent brightness from stars is a tiny fraction of what we get from the Sun. But modern instruments are very good at measuring it very precisely. The equation to determine the intrinsic luminosity is the same.

For Vega, the measured luminosity at 25 light years gives us the luminosity for the star at 40 times the Sun's power.

For the Sun and for Vega, and for all the stars we have seen so far, we know the apparent brightness and distance to the star via parallax. The inverse square law gives us the intrinsic luminosity. If we know the intrinsic luminosity and apparent brightness, the same equation gives us the distance. In other words, if we know the luminosity of a star, we can calculate its distance. This is the basic concept around 'Standard Candles'. We'll discuss this a little more in a few minutes. **]**

Astronomers use a more complex set of classifications for calculating brightness called Magnitudes and absolute magnitudes at 10 parsecs. But, for our purposes, we'll stick to Luminosity.

Pollux - 34 light years

Getting back to stars, here's Pollux, a bright orange star. In 2006, it was confirmed to have an orbiting planet.

Arcturus – 36.7 light years

Arcturus is an even brighter orange star. In fact, it is the fourth most luminous star in the Sun's neighborhood.

GJ1214 - 40 light-years

GJ1214 is a dim reddish star. Observations by Hubble in 2009 discovered GJ1214 b, a water-world planet enshrouded by a thick, steamy water rich atmosphere. Here we see an artist's conception of the new water planet.

Capella - 42.2 light-years

Capella has a rich yellow color and is the third brightest star in the northern hemisphere, after Arcturus and Vega. Closer examination finds that Capella is actually four stars organized as two binary systems.

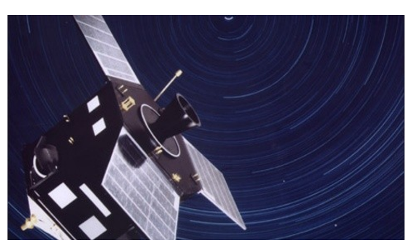
Castor - 49.8 light years

Castor is actually three sets of binary systems with some bright yellow and some dim red stars.

Hipparcos

Since 1838, many astronomers have spent decades measuring star parallaxes, but the work is so painstaking that up until 1989, only a few hundred were measured. That's out of a total population of over 1,500 stars within 60 light years from us.

In 1989, however, the European Space Agency launched a spacecraft called **Hipparcos.** It was specially designed to accurately measure parallaxes without all the interference from the Earth's atmosphere. It did so for over 118,000 stars.



Hipparcos is accurate to within 5% to 10% for stars within 650 light years.

> **[Additional info:** Hipparcos and subsequent parallax measuring satellites have mapped a total of 2 and a half million stars out to hundreds of light years.**]**

Let's take a look at a few of these.

HD 189733 - 63 light years

HD 189733 is a binary star system with the primary star being a dim orange star and the secondary star being a dim red star. As we zoom into the star, you can see the Dumbbell planetary Nebula. We'll cover these objects in the next section.

Hubble has made the first detection ever of an organic molecule in the atmosphere of a Jupiter-sized planet orbiting this star. The molecule is methane. Under the right circumstances methane can play a key role in prebiotic chemistry — the chemical reactions considered necessary to form life as we know it.

Aldebaran – 65 light years

Aldebaran is a very bright red star. It may have a **brown dwarf** companion. A brown dwarf is a star that did not have enough mass to trigger fusion, so it only produces light via conventional means. This makes it very hard to see.

Mizar – 82 light years

Mizar is a bright white star. It is famous for being the first binary star system discovered. Galileo studied it extensively. These two stars take thousands of years to revolve around each other, so they were not seen to be rotating around each other in those days. It wasn't until the early 1800s, that binary stars rotating around each other were seen. This was the first evidence that gravitational influences existed outside our solar system.

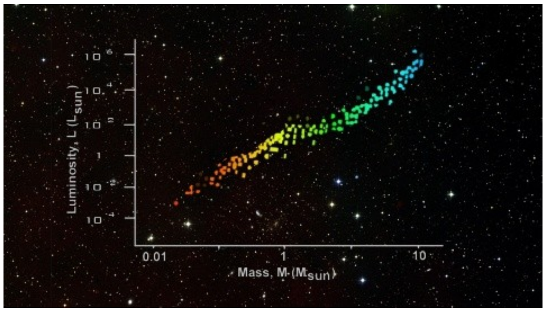
Mass of a star

> **[Music:** *We return to von Weber's "Der Freischütz - Ouvertüre".***]**

Half of all stars are binary systems or larger. In the 1900s, they were key to measuring a stars mass.

> **[Additional info:** If you recall from our section on the Solar System, we determine the mass of an object by observing its gravitational effects on other objects.**]**

Once the mass of enough binary stars were calculated, it became possible to plot Mass vs. Luminosity on a graph. Here's what they found.



Instead of having any combination of mass and luminosity, we see that stars fall on a line from low-mass / low-luminosity to high-mass / high luminosity. But it is not linear. Each time the mass is doubled, the luminosity goes up 11 times. This relationship seems to work for most stars that aren't too massive.

Mass vs. Luminosity

Let: M = Mass of the star
M_{sun} = Mass of the Sun
L = Luminosity of the star
L_{sun} = Luminosity of the Sun

We fit the graph with:

$$L/L_{sun} = a(M/M_{sun})^b$$

Where:

$a = .23$ and $b = 2.3$ when $M < .43M_{sun}$
$a = 1$ and $b = 4$ when $.43M_{sun} < M < 2M_{sun}$
$a = 1.5$ and $b = 3.5$ when $2M_{sun} < M < 20M_{sun}$
$a = 1$ and $b = 1$ when $20M_{sun} < M$

Note that this is an empirical relationship. We don't start with an equation and plot its graph. We observe events to create the graph and then find an equation that would have created a graph that looks the same or 'fits' what we observed.

Now back to the stars again.

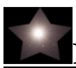
Spica – 260 light years

Spica is a blue star and the 15th brightest star in the nighttime sky. It's a close binary star system whose components orbit each other every four days. They are so close together that they cannot be resolved as individual stars through a telescope.

Mira - 350 light-years

Mira is a very high proper motion red star that is shedding an enormous trail of material. The tail stretches a startling 13 light-years across the sky. It has released enough material over the past 30,000 years to seed at least 3,000 Earth-sized planets.

[Additional info: It is zipping along at 291,000 miles per hour. This creates the bow shock, in front of the star. This is similar to the one we saw our Sun creating in our section on the Heliosphere. Mira is also what's called a pulsating variable star. It dims and brightens by a factor of 1,500 every 332 days. Sometimes it is even bright enough to see with the naked eye.**]**



Polaris 431 light years

Polaris is our current day 'North Star', for it lies less than 1.0° from the north celestial pole. It is a double star system with one being a supergiant. The supergiant is a classic Cepheid variable star. Cepheids are a critically important kind of star for our distance ladder. I'll talk more about them in a minute when we come to Delta Cephei – the first Cepheid star completely analyzed.

Antares 604 light years

Antares is a bright red star - the sixteenth brightest star in the nighttime sky. The size of Antares has been calculated using its parallax and angular diameter. Its radius is 822 times larger than our Sun's.

Light

We have now visited a number of stars from our local neighborhood. We started with the nearest stars where parallax measurements from earth bound telescopes were good enough. We then moved out to the further reaches of our neighborhood using Hipparcos based parallax measurements. But now, we are at distances where parallax measurements become increasing problematic even for space telescopes like Hubble **[**due to the extremely small parallax angles involved.**]**

We have around 3 million stars within parallax reach, but this is a tiny fraction of the hundreds of billions of stars in the Milky Way. If all we had was parallax, we'd know very little about our galaxy and virtually nothing about the universe beyond. But the only other thing we can get from a star is its light.