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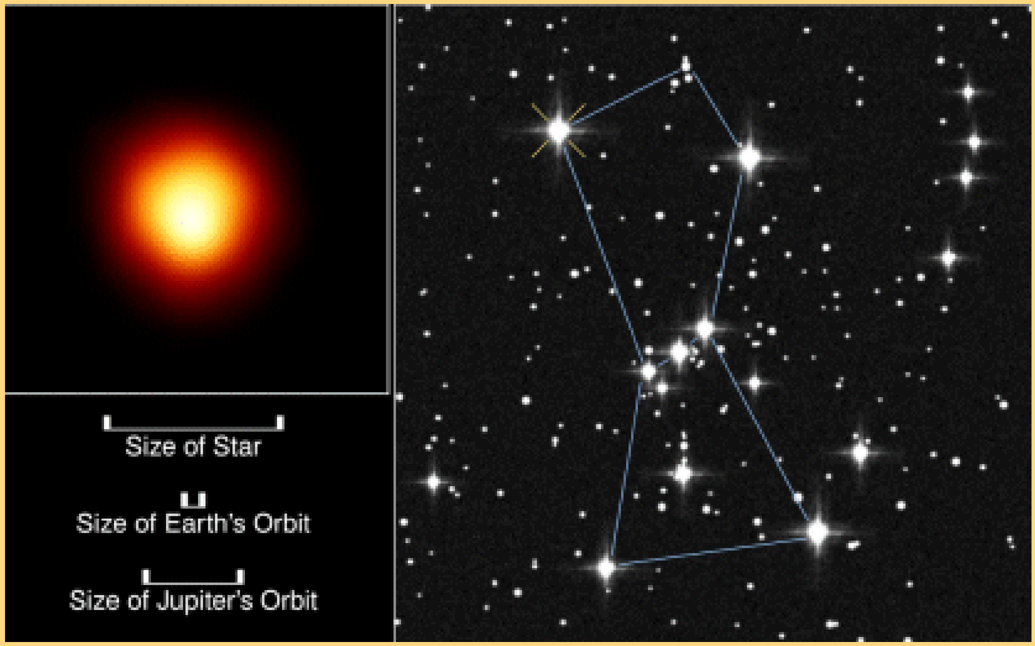
Variable Star Of The Month

December, 2000: Alpha Orionis (Betelgeuse)



Atmosphere of Betelgeuse - Alpha Orionis
Hubble Space Telescope - Faint Object Camera
January 15, 1996; A. Dupree (CfA), NASA, ESA

From the city or country sky, from almost any part of the world, the majestic figure of Orion dominates overhead this time of year with his belt, sword, and club. High in his left shoulder (for those of us in the northern hemisphere) is the great red pulsating supergiant, Betelgeuse (Alpha Orionis 0549+07). Recently acquiring fame for being the first star to have its atmosphere directly imaged (shown above), Alpha Orionis has captivated observers' attention for centuries.

Betelgeuse's variability was first noticed by Sir John Herschel in 1836. In his *Outlines of Astronomy*, published in 1849, Herschel wrote "The variations of Alpha Orionis, which were most striking and unequivocal in the years 1836-1840, within the years since elapsed became much less conspicuous…" In 1849 the variations again began to increase in amplitude, and in December 1852 it was thought by Herschel to be "actually the largest [brightest] star in the northern hemisphere". Indeed, when at maximum, Betelgeuse sometimes rises to magnitude 0.4 when it becomes a fierce competitor to Rigel; in 1839 and 1852 it was thought by some observers to be nearly the equal of Capella. Observations by the observers of the AAVSO indicate that Betelgeuse probably reached magnitude 0.2 in 1933 and again in 1942.

At minimum brightness, as in 1927 and 1941, the magnitude may drop below 1.2. Betelgeuse is a semiregular pulsating red supergiant. It is believed to be at least the size of the orbit of Mars and at maximum diameter may possibly equal the orbit of Jupiter. The star is one of the largest known; spectroscopic studies show that the diameter of the star may vary by about 60% during the whole cycle, a difference considerably larger than the radius of the Earth's orbit!

Betelgeuse is not only among the largest, but also one of the most luminous stars of its class.

At a distance of roughly 425 light-years, it is the seventh brightest star in the northern hemisphere. Its diameter, based on the new distances recently reported by the European Space Agency satellite HIPPARCOS, is about 1500 times the diameter of our Sun (Press Release, 1996). Betelgeuse has a luminosity of about 14,000 Suns at maximum and 7600 Suns at minimum. The peak absolute magnitude of Betelgeuse is about -5.6. The surface temperature is that of a typical M-type red supergiant, about 3100 degrees Kelvin. Only about 13% of the radiant energy is emitted in the form of visible light, so if our eyes were sensitive to radiation at all wavelengths, Betelgeuse would appear as the brightest star in the sky. (Burnham, 1966).

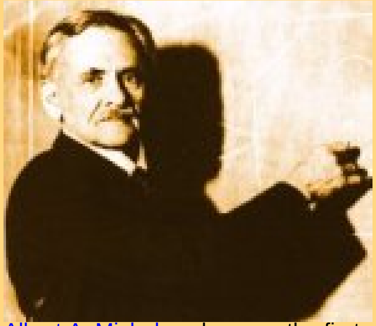
From the island of La Palma in the Canaries archipelago, this image clearly shows Orion with Betelgeuse in the top left corner.
Credit: A. Vannini, G. Li Causi, A. Ricciardi, A. Garatti

The outer edge of Betelgeuse's circumstellar envelope extends well over a trillion kilometers from the star so light from the star takes a good two months to escape the gas shell. In the outer reaches of this vast globe, the density is extremely low. In volume, Betelgeuse exceeds the Sun by a factor of at least 160 million even at minimum. Yet the actual mass of the star is probably no more than about 20 solar masses, which means that the average density must be in the range of .00000002 to about .00000009 the density of our Sun. Such star material has a density of less than one ten-thousandth the density of ordinary air. A star of such tenuous nature has often been called a "red-hot vacuum" (Burnham, 1966).

Lights, Camera, Action . . . Betelgeuse takes the stage!

Since the turn of the century, Betelgeuse has held a pivotal role in stellar research, observational tests, and photographic imaging due to its enormous size and bright luminosity.

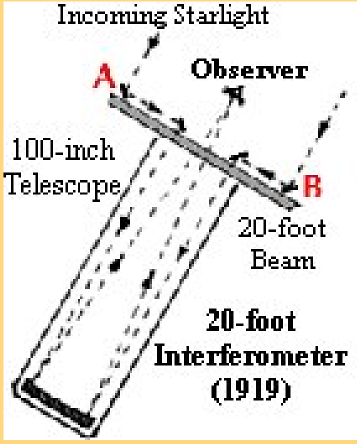
Michelson's Beam Interferometer measures the diameter of Betelgeuse (1920)



Albert A. Michelson became the first American to receive a Nobel Prize in Physics, 1907.

In 1920, Betelgeuse became the first star to have its diameter measured by means of the beam interferometer invented by Albert A. Michelson. This instrument was first tested on the 100-inch telescope at Mt.Wilson on December 13, 1920. Betelgeuse was selected as the first test object since theoretical calculations had suggested that the star was unusually great in size. The experiment was a success and the apparent angular size of Betelgeuse was found to average about .044 arcseconds.

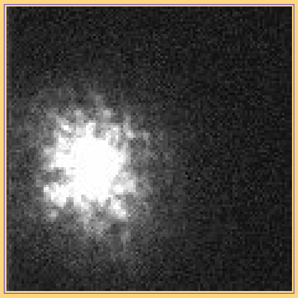
It is important to remember that direct interferometer measurements can only be used with large stars. The majority of stars rely upon more indirect methods of determining stellar sizes. Currently, sophisticated interferometers are making great advances in astronomy. These instruments, which use a cluster of widely-spaced telescopes whose separate observations are combined into a single image, improve the resolution of structures on stellar surfaces. The Keck Interferometer, IOTA (Infrared Optical Telescope Array), and CHARA (Center for High Angular Resolution Astronomy) are just several examples of interferometers in use today.



Michelson's Beam Interferometer

The theory and use of this instrument is explained in optical texts; basically it consists of a system of mirrors which can be moved to the opposite ends of a log beam mounted across the mouth of the telescope. The end mirrors both receive the light of the star and direct it into the main tube, thus increasing the effective aperture of the telescope by 8 times or more. When the images from the two end mirrors are superimposed in the field of the telescope, a pattern of interference fringes is created. As the mirrors are moved alternately toward and away from each other the pattern is seen to change and vanishes entirely at one point. The separation of the mirrors required to cancel out the interference fringes is carefully measured, and an optical formula then gives the diameter of the light source, in fractions of a second of arc.

Speckle Interferometry reveals brightness variations on Betelgeuse (1975)



This is what a star really looks like from the surface of the earth. Due to atmospheric turbulence, stars appear to "twinkle". Click on the image of Betelgeuse above to see how the wind and air affect our view (ten times slower than actual speed).
Credit: Applied Optics Group (Imperial College), Herschel 4.2-m Telescope

Betelgeuse is one of the few stars in the sky whose actual disc is theoretically within range of detection by large reflectors; the apparent angular diameter is about .05 arcseconds whereas the theoretical resolving power of a 200-inch reflector is about .02 arcseconds. Owing to the incurable unsteadiness of the Earth's atmosphere, however, the performance of large ground-based reflectors never reaches the theoretical limit. On the other hand, through a combination of special photographic techniques and computer-enhancement of images, some actual detail on the disc of Betelgeuse has been made visible for the first time, at the Kitt Peak Natioanl Observatory, in 1975. Using the 158-inch Mayall reflector with an image-intensifier, astronomers obtained photographs which were reduced to magnetic data and fed into the Interactive Picture Processing System (IPPS) which can be adjusted to enhance any feature present in the images. After taking hundreds of short exposures that "froze" atmospheric distortion, astronomers reconstructed a single sharp image of Betelgeuse from them. This technique, called speckle interferometry, revealed brightness variations on the disk of this supergiant star. The mottling of the disc and the large dusky areas revealed by this method are evidently true features on the star; they represent areas of different temperature and light intensity, comparable to the bright flares and dark spots seen on our own Sun.

Speckle Interferometry reveals dust and companions around Betelgeuse (1985)

Reconstructed from interference patterns this false-color image of Betelgeuse reveals a "hot spot" that could correspond to a huge column of upwelling gas.
Image courtesy David Busher and the William Herschel Telescope.

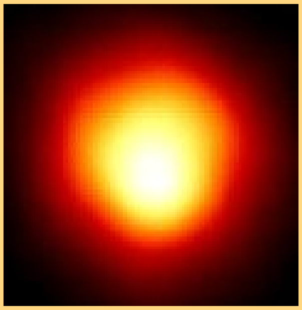
Francois and Claude Roddier constructed an image of Alpha Orionis and found indications of dust close to the red supergiant star. Their data were gathered in 1980 with an interferometer and the Canada-France-Hawaii Telescope. To explain Betelgeuse's lopsided appearance, they favor the idea that a large fraction of the recorded light comes from an irregular dust envelope close to the stellar disk. Details concerning their work are reported in *Astrophysical Journal Letters* for August 1, 1985.

However, dust is not the only thing surrounding Betelgeuse. Margarita Karovska, an associate of the Roddiers' now based at the Harvard-Smithsonian Center for Astrophysics, announced in 1985 that the famous red supergiant has two close companions. Her results are based on speckle interferometry work done in the early 1980s at Kitt

Peak, Arizona, and Cerro Tololo, Chile. It revealed that the inner of the two stars orbits Betelgeuse every two years or so at a mean distance of about 5 astronomical units and little is known about the outer companion except that it lies some 40 or 50 astronomical units from Betelgeuse (December, 1985, *Sky and Telescope*).

Hubble Space Telescope Captures First Direct Image of a Star (1995)

The first direct picture of the surface of a star other than the Sun, was made in 1995 with the Faint Object Camera on the Hubble Space Telescope of our now famous supergiant Betelgeuse. The Hubble image reveals a huge ultraviolet atmosphere with a mysterious hot spot on the stellar behemoth's surface. The enormous bright spot, more than ten times the diameter of Earth, is at least 2,000 Kelvin degrees hotter than the surface of the star.



Atmosphere of Betelgeuse directly imaged in ultraviolet light with the Faint Object Camera on March 3, 1995. Courtesy A. Dupree, R. Gilliland, and NASA.

The image suggests that a totally new physical phenomenon may be affecting the atmospheres of some stars. Follow-up observations will be needed to help astronomers understand whether the spot is linked to oscillations previously detected in the giant star, or whether it moves systematically across the star's surface under the grip of powerful magnetic fields.

The observations were made by Andrea Dupree of the Harvard-Smithsonian Center for Astrophysics in Cambridge, MA, and Ronald Gilliland of the Space Telescope Science Institute in Baltimore, MD, who announced their discovery at the 187th meeting of the American Astronomical Society in San Antonio, Texas.

The Semiregular Supergiant

Click above image for a Long term light curve of Alpha Orionis.

The light variations of Betelgeuse are not completely understood, however since the star has been studied extensively, there are theories that describe the observed phenomena. Astronomers think the outer layers of the star expand slowly for several years and then shrink again, so the surface area alternately increases and decreases, and the temperature rises and falls, making the star brighten and dim. Red supergiants pulsate this way because their atmospheres are not quite stable. When the star is smallest, the atmosphere absorbs a bit too much of the energy passing through it, so the atmosphere heats and expands. As it expands, it becomes thinner. Energy then passes through the outer layers more easily so the gases cool, and the star shrinks again.

A Harvard-Smithsonian Center for Astrophysics Press Release announcing the first direct image of a star (Betelgeuse), suggests that this event holds new implications for stellar research. Researchers said that this new picture of Betelgeuse suggests that a totally new physical phenomenon may be affecting the atmospheres of some stars. "What we see on Betelgeuse is completely different from what occurs on the surface of the Sun," said Dupree, a senior scientist at the CfA. "Instead of lots of little sunspots, we find an enormous bright area more than 2,000 K degrees hotter than the surrounding surface of the star." Until follow-up observations of Betelgeuse are completed, however, astronomers won't know the mystery spot's true nature--or how it formed.

Dupree explains that the spot might change position over time. Dupree and colleagues using the International Ultraviolet Explorer found a 420-day period, during which the star oscillates, or "rings" like a bell. The oscillations, thought to be caused by turbulence below the surface of the star, might cause changes in the bright spot. Future oscillations might spur other bright spots on different regions of the star's surface, causing it to wink on and off like blinking lights on a Christmas tree, said Dupree. Alternatively, the spot might move systematically across the star's surface, which would imply that the star has magnetic fields strong enough to hold the bright spot's hot gas in position. Either scenario would lead astronomers to re-think completely current ideas of how stars evolve. "We hope this work will also pave the way for a generation of space interferometers," said Dupree. Such instruments would greatly improve the resolution of structures on stellar surfaces.

The Class of Semiregulars

Betelgeuse is classified as a semiregular variable type SRc. The distinctions between Mira stars, Semiregulars, Irregulars, and RV Tauri stars is a bit foggy and are usually discussed together due to their similarities. Since Betelgeuse is classified as a semiregular variable our discussion will focus on these types of stars. Semiregular variables are post main sequence cool (red) giant and supergiant stars. There are four groups of semiregular variables (SRa, b, c, and d). The descriptions of these classes follow:

SRa These stars have periods longer than 35 days, V amplitudes less than 2.5 magnitudes, and regular variability. They are similar to Mira stars in their periodicity but are distinguished by their smaller amplitude. A typical member of this subgroup is the star Z Aqr.

SRb These are also small amplitude stars but with less regularity in their light variations than the SRa stars. The SRb stars have periods longer than 20 days and V amplitudes less than 2.5 magnitudes. Although the form of a period is evident, it becomes inoperative from time to time. An example of an SRb star is Z Uma.

SRc These are the Supergiants which are extremely luminous stars. They have low amplitudes and occasional standstills. Betelgeuse is classsified as an SRc type variable.

SRd Yellow giants and supergiants of spectral classes F-K: not a very homogeneous group. They are much hotter than the other semiregulars and show irregularities at times.

Observer's Challenge

Orion Star Colors
Credit & Copyright: David Malin
Temperature determines a star's color which is dramatically illustrated above in the star trails from Orion.

Betelgeuse is a difficult star to observe due to its redness, lack of well-placed (i.e. close) comparison stars, and small amplitude. It is also best to compare a red star with another red star at about the same altitude. Although a challenge to observe, it is encouraging that Betelgeuse is so bright and easy to find. Observers could create an observing program in which you observe Alpha Ori in the coming months once every week. Try not to compare your observations with those in our Quick Look files or light curve generator to avoid bias in your estimate and see if you can really detect the light variability in this supergiant. Photoelectric photometry observers are especially encouraged to observe this star of small amplitude. In fact, Betelgeuse has been in the AAVSO Photoelectric Observing Program since the early 1980s. John Percy, an active AAVSO member, suggests a good Alpha Ori observing program in this email to the AAVSO Discussion forum. When observing for the AAVSO, please use magnitude 0.5 for Procyon (alpha CMi) and a magnitude of 1.1 for Aldebaran (alpha Tauri). An AAVSO a-scale chart is also available. Next year, with the first sight of Orion in your sky, be sure to observe Betelgeuse again. Send in your observations to the AAVSO to be incorporated into our International Database. For more help on how to observe variable stars visit our telescope simulator, or contact the AAVSO.

Betelgeuse, Betelgeuse, Betelgeuse

The name “Betelgeuse” is a corrupt derivative of the original Arab nomenclature due to repeated transcriptions and transliterations over many centuries. According to George A. Davis (S&T April 1995, 237) most people agree that the last syllable of the name comes from the Arabic noun *al-Jawza’*. The “original” meaning of this word designates a black sheep with a white spot in the center of its body, however scholars have interpreted the meaning to come from a similar Arabic word, *jauz*, which means “the center of anything” or “the central one”. Davis believes that the true origin of the name is *Yad al-Jawza’*, “the forefoot of the white-belted sheep,” one diacritical point missing under the *ya* in Yad resulting in the transliterated syllable *bad* or *bed*. The change of a *d* to a *t* needs no explanation, and so evolved the current name, "Betelgeuse".

On an interesting cinematical side note, this "letter to the editor" by Michael McDowell from Los Angeles, California, appeared in the April 1989 issue of *Sky and Telescope* magazine.
Betelgeuse: The Movie

> I’d like to assure all *Sky and Telescope* readers that the film *Beetlejuice*, currently in videocassette release from Warner Bros., Inc., does indeed take its title from the red-giant star in Orion. In fact, where the name appears in writing in the film it is rendered in its official form rather than its phonetic one. I should know I wrote the original script!
>
> During the four years I spent with the project in Hollywood, I was repeatedly pleased   and somewhat astonished   by people who responded to the title *Beetlejuice* with the question, “Oh, you mean like the star?” Somebody even suggested that the sequel be named *Sanduleak -69 202* after the precursor to Supernova 1987A.

We hope you enjoy this beautiful star for the next couple of months. Try not to confuse it with any *red blinking noses* that may be in the area. ;)
Happy Holidays everyone!!

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- Star Gazer by Jack Horkheimer, "A Great Big Red Star For Valentine's Day, Slowly Beating Like A Giant Cosmic Heart"
- Betelgeuse Poem
- A Brief History of Stellar Interferometry

This month's **Variable Star of the Month** *was prepared by Kate Davis, AAVSO Technical Assistant, Web.*

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