

Epsilon Aurigae: a rare stellar eclipse

Epsilon Aurigae is the fifth brightest star in the northern constellation Auriga. It is the eclipsing binary star with the longest known orbital period, showing a single eclipse every 27.1 years. Eclipse duration is extremely long: it takes nearly 2 years for the companion to pass the star for an external observer's line of sight. For the last two centuries the nature of the eclipsing object was not reliably explained, until its long-awaited eclipse in 2009-2011.

Epsilon Aurigae (ϵ Aur, 7 Aur, SAO 39955, HD 31964) is located 3 degrees from Capella (alpha Aurigae) in a small triangular group of stars known as "The Kids". The main star of the epsilon Aurigae star system is a post-AGB hot-end yellow giant F0 II star with a mass of about 3 times our Sun (Hoard, 2010) and a diameter of ~ 135 times (Chadima, Harmanec, et al., 2011). The Epsilon Aurigae system is perhaps the most interesting eclipsing star system. It has puzzled astronomers for over 170 years.

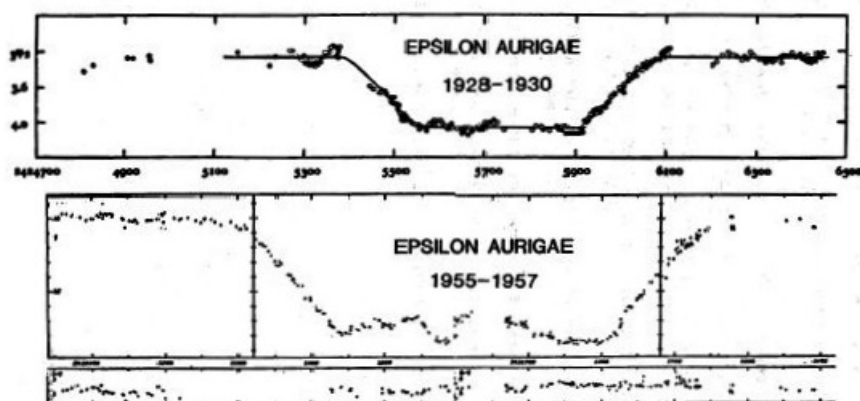
Many theories have been put forth as to what the eclipsing body is. A black hole or gigantic star are just a few. Most popular idea is that a large cloud of dust or gas orbiting the host star. But if that is true something massive must be embedded to hold the cloud together from the inside. The previous eclipse took place back in 1982-1984. The recent was in 2009-2011, when a new generation of telescopes had been prepared on this stellar enigma in an effort to unlock its mystery. This was only the seventh documented eclipse in history (2010, 1983, 1956, 1930, 1902, 1874 and 1847).

There is another interesting extremely long-period eclipsing binary star system known - 32 Cygni. Its brightness varies from 4.0 to 4.2 magnitudes every 1148 days, or 3.1 years. But the eclipse lasts only 11 days (Jancart, S. et al., 2005). Implying that to the epsilon Aurigae star system one would expect an eclipse to last less than 11 days, possibly even just hours. Instead, in fact, we observe a 2-years-long eclipse.



The discovery of epsilon Aurigae

The earliest mention of the variability of epsilon Aurigae was in 1821, by an amateur astronomer, High Minister Fritsch of Quedlinburg, Germany. Johann Fritsch was the first to note the variability, when the star was likely in the midst of a deep eclipse. This fact has been reflected in a written notice (Fritsch, 1824).



Epsilon Aurigae eclipse observations in 1928-1930 and 1955-1957

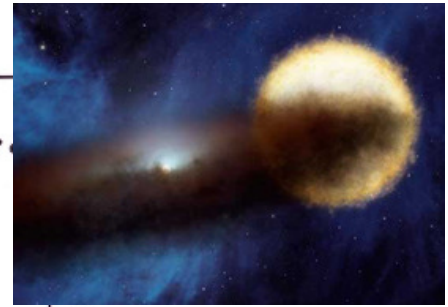
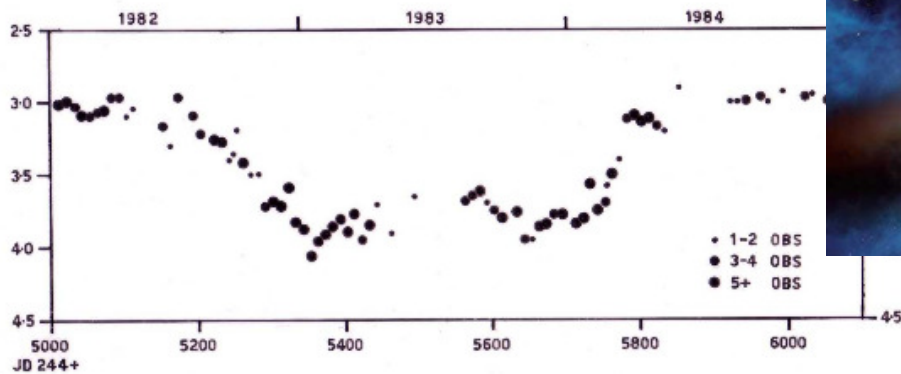
The German astronomers Argelander and Heis both began its observing once every few years around 1842-1843. The data showed that the star became significantly fainter around 1847. By September of 1848, epsilon Aurigae became significantly brighter again, reaching its near-normal brightness by the end of that year. Observers later in the 19th Century recorded another dimming event in 1874-1875, and another in 1901-1902. (*historical details are from the AAVSO article http://www.aavso.org/vsots_epsaur by Dr. Matthew Templeton*)

After this initial observation by Fritsch, several other observers obtained data on epsilon Aurigae, but until 1903 the dimming wasn't confirmed to occur every 27.1 years (Ludendorff, 1903). Later in 1912, H.N. Russell published the first analytic methods for binary star analysis, and in 1915 Harlow Shapley applied the method to

epsilon Aurigae with distressing results: the companion was as massive as the primary F supergiant star, but undetected in photometric and spectroscopic observations!

Untangling the mystery

Several authors have attempted to explain the eclipse phenomenon, sometimes using the most exotic objects in the universe. Decade after decade, great names of 20th-century astrophysics tried to account for this behavior. During the 1928–30 eclipse, Dean B. McLaughlin and others detected spectroscopic Doppler shifts that indicated a vast rotating object crossing in front of the F supergiant. In 1937 an attempt to explain the phenomenon was made by Gerard Kuiper, Otto Struve, and Bengt Strömgren. They suggested the system was an eclipsing binary composed of an F2 primary star and an extremely cool star that they described as "semitransparent" orbiting the primary. In 1965 Su-Shu Huang suggested an edge-on thick disk as the eclipsing body. These theories could not explain the mid-eclipse re-brightening which was clearly noticeable during all known epsilon Aurigae eclipses. In 1971, Robert Wilson introduced a thin tilted disk with a central opening, suggesting that this model could most easily describe all of the observed effects of the eclipses, particularly.

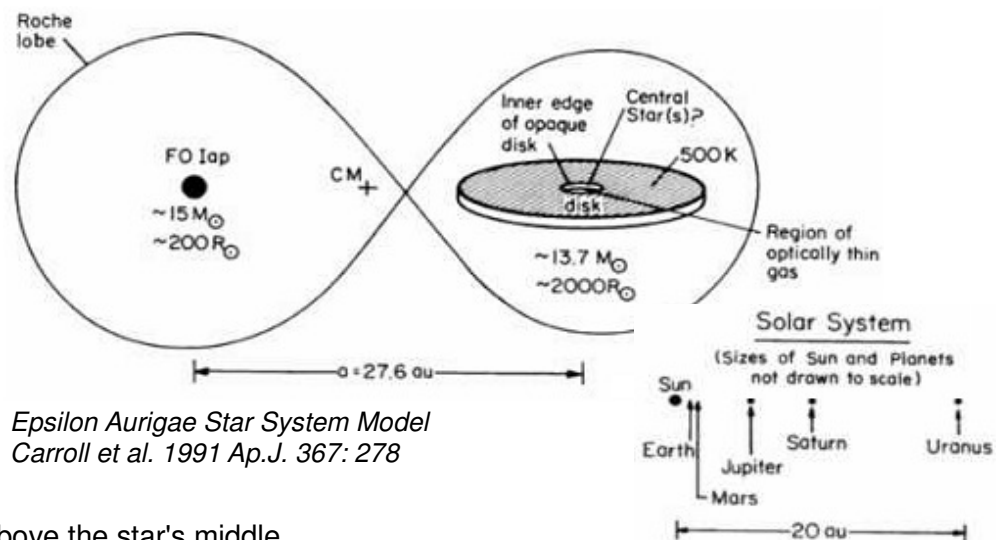


Epsilon Aurigae eclipse observations in 1982-1984 with the mid-eclipse re-brightening clearly visible on the plot. Top right: artist's impression of epsilon Aurigae system. Credit: NASA / JPL-Caltech

Flat-bottomed eclipses of 2-years duration and their depth (2.9 to 3.8) optically suggest that the cold disk covers half the surface area of the F star (Huang 1965). A lot of information was collected during the eclipse of 1982 -1984. At the end of the campaign, in 1985 a workshop was held at the American Astronomical Society meeting in Tucson, Arizona, where tens of papers were presented. Despite that, the mystery still remained unresolved. Kopal presents the first ideas of a disk existing in the system in 1954. That was in remarkable agreement with current observational evidence. He proposed that the companion to the F-star is a flat, semi-transparent ring (disk) with a radius of ~ 6 AU and an opacity of 0.8. Kemp et al. (1986) analyzed polarimetry of the 1984 eclipse and argued that the disk is inclined 2-5 degrees from its orbital plane.

Later, Gary Henson, Kemp's PhD student, published all of the polarization data in his thesis and analyzed the out-of-eclipse variations. From Henson's work, there is evidence to support the F-star being a non-radial pulsator, thereby explaining the secondary variations in the light curve. According to this data, it was determined that the disk was tilted with respect to the orbit, and that the orbit crosses the F-star just above the star's middle.

(Source used: <http://www.citizensky.org/book/export/html/1033>)

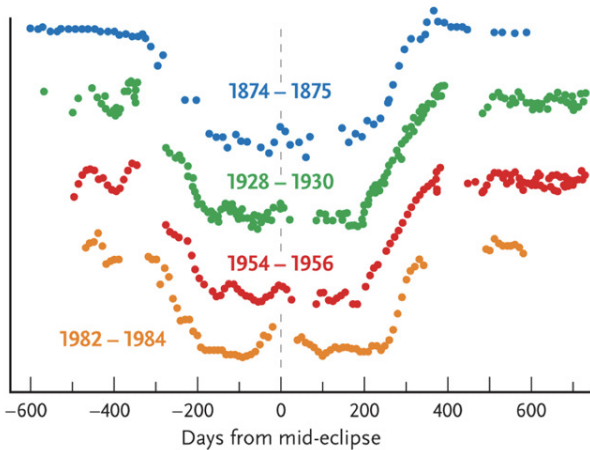


To hold the disk together, astronomers believe there must be at least one star at its center, yet none is visible. Modern theory estimates disk's diameter of ~ 8 AU, made of dusty material. Still a strange behavior: near the mid-point of the eclipse, the system appears to suddenly increase in brightness for a short time. Long period between epsilon Aurigae eclipses means each cycle taken up by new observers and technologies. The

most recent eclipse began in autumn of 2009, so another campaign was planned. One of the remarkable advances since the 1983 eclipse of epsilon Aurigae is the significant progress in interferometric imaging. A good literature review on epsilon Aurigae before the 2009 eclipse subject can be found at <http://www.citizensky.org/book/export/html/1349>

The 2009-2011 eclipse: hardware progress made it all possible

The eclipse started in early September 2009. Having a year ahead, scientists had quite a bit of time to perform wide range of measurements and reconstruct the system with properties explaining the behavior. It is not an single night event, where the data have to be collected within minutes/hours, getting it lost otherwise. Seeing this eclipse in detail has only now become possible. For the first time, astronomers have directly



Eclipse durations measurements of epsilon Aurigae. Courtesy of CitizenSky.org.

observed the mysterious dark companion in a binary star system of epsilon Aurigae. Using an instrument developed at the University of Michigan, scientists have taken close-up pictures of Epsilon Aurigae during its eclipse.

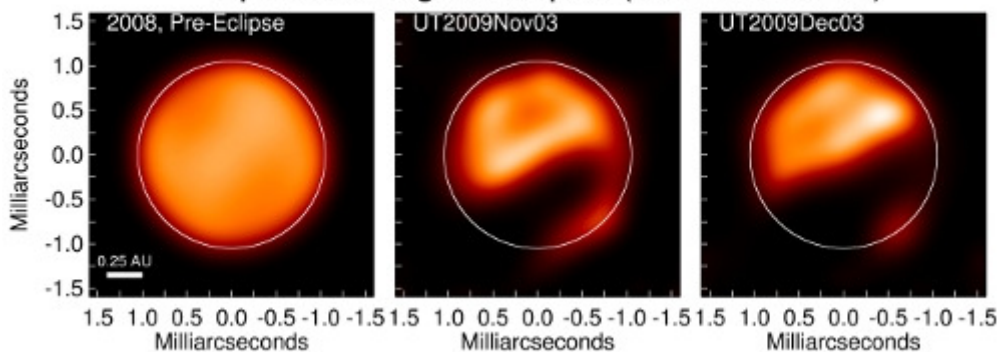
A series of images obtained at the Center for High Angular Resolution interferometer with the Michigan Infrared beam Combiner (CHARA-MIRC) at Mt. Wilson show the progression of the 2009-2010 eclipse of epsilon Aurigae, the dark disk and its substructure (see image below).

John D. Monnier led the creation of the MIRC, which uses an "interferometry" approach to combine the light from six telescopes at the CHARA array* at Georgia State University. Such an amplification is equal to the light gathered through a device ~100 times larger than the Hubble Space Telescope.

The pre-eclipse observations in 2008(left) show the primary F-star as a nearly uniformly illuminated 2.27 milliarcsecond circle. The November 2009 observation (centre) shows the

shadow of the disc (outlined in a white ellipse) around second contact and the December 2009 observations (right) show that nearly 50 percent of the stellar surface is obscured by the eclipsing object. Image: John D. Monnier, University of Michigan, (*Nature*, 8 April 2010). The image was obtained using the interferometric technique, an idea that incorporates computer control and laser connections among multiple telescopes to achieve signal equivalent to one giant telescope.

Epsilon Aurigae Eclipse (CHARA-MIRC)



Images of epsilon Aurigae on the sub-milliarcsecond scale, during the ingress: 2009 (November and December). All images were acquired using CHARA-MIRC, the Michigan Infrared Combiner. Image Credit: John D. Monnier, University of Michigan

The **CHARA Array** (The Center for High Angular Resolution Astronomy) is an optical interferometer located at the Mount Wilson Observatory (California). The array is formed from six 1-meter telescopes arranged along three axes with a maximum separation length of 330 m, operated by the Georgia State University (GSU). It is among the most powerful facilities of its kind in the world for studying stars and stellar systems at resolutions not previously available. The light beams travel through vacuum tubes and are combined optically, with movable mirrors to keep the light in phase as the earth rotates. CHARA began scientific use in 2002. In the infrared, the array has an interferometric imaging resolution of 0.0005 arcseconds.

(Source: <http://www.chara.gsu.edu/CHARA>; Wikipedia)

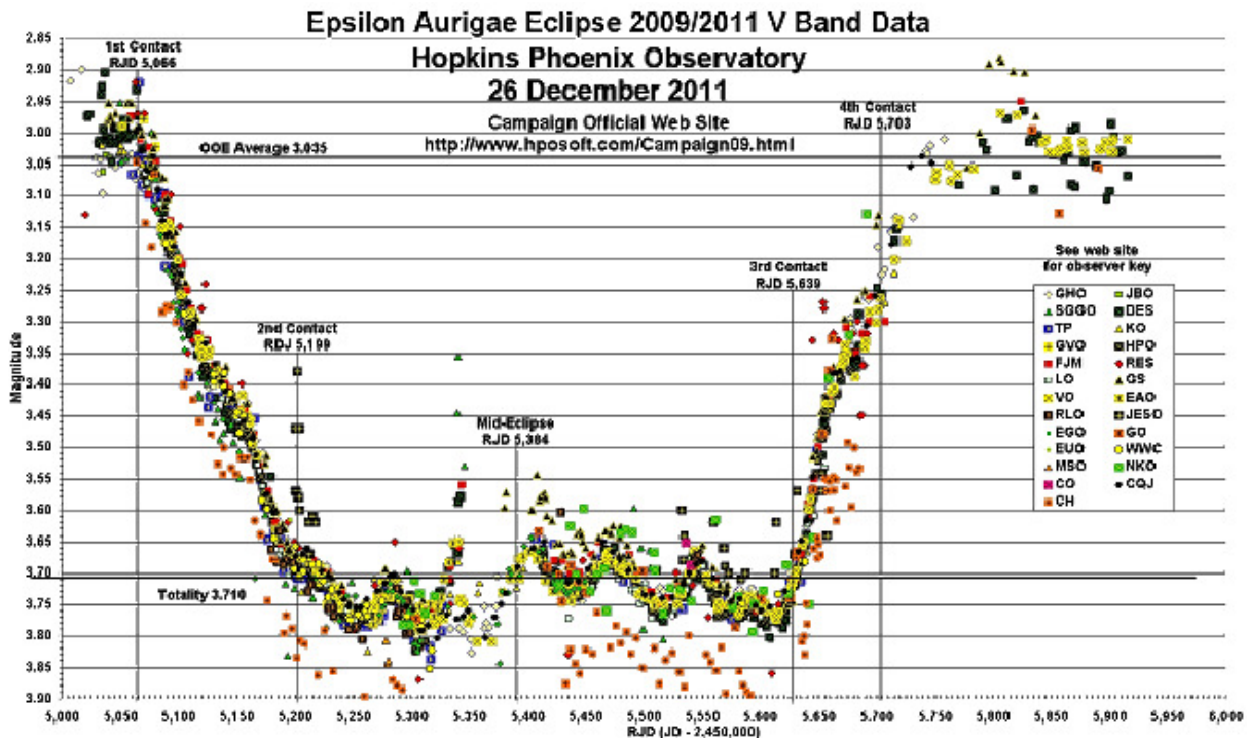
This data was also confirmed with the direct observation of the current eclipse from an international team lead by Brian Kloppenborg at the University of Denver. The new images show that this is the case: a geometrically thin, dark, dense, but partially transparent cloud can be seen passing in front of epsilon Aurigae. The images taken over a month clearly show the black silhouette of the disc beginning to move across the surface of the primary star. The size of the disc was measured at about 2.4 billion kilometers across, which is almost two times larger of the orbit of Jupiter. Though disk's mass was estimated to be ~ 0.1 that of Earth. It is enough for the disc to hide the brighter and hotter B-type star of 5.9 solar masses inside. The disc effectively blocks most of its light from an outermost observer.



Artist's concept of epsilon Aurigae system.

Credit: Casey Reed, S&T

In May of 2006, Dr Robert Stencel of the University of Denver, who has been studying epsilon Aurigae since the 1980s, along with amateur astronomer Jeff Hopkins created a website to cover all the observations and analysis of the 2009-2011 eclipse. The website is called "*International Epsilon Aurigae Campaign 2009*". The page is alive, and now it provides a wealth of data gathered by observers all over the world, as long as published papers list. Over a thousand amateur observers sent their measurements in order to contribute to the campaign. As the result, a combined light curves in different bands were published covering all eclipse's phases. The website is parked at <http://www.hposoft.com/Campaign09.html> Below is the light curve covering the visual band measurements of epsilon Aurigae eclipse in 2009-2011.



The whole story is a really good example of how combining of efforts of many scientists and amateurs can lead to a true discovery. Though the research is not over, the concept of dusty disk around of the companion star is considered proven after a more than 170-years way...

References for further reading:

Ivan Adamin

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