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Variable Stars

Variable Star of the Season, January 2008

Epsilon Aurigae

The end of the year is the prime observing season for one of the most enigmatic bright variables in our sky -- the mysterious eclipsing binary **epsilon Aurigae**. Now is an exciting time to familiarize yourself with this fascinating star, as we countdown to a rare eclipse starting in mid-2009. Although epsilon Aurigae has been a known binary for over a century, it isn't yet known what exactly is eclipsing what! The curious light curves of the eclipses have been studied in detail, but they're so infrequent that new knowledge is slow in coming -- with a period of 27.12 years, only three or four occur each century. Although binary star modelers have an idea of what this system is, astronomers are hopeful that a full understanding of this system will come after the end of the next eclipse. It's been a long wait since the last one, and the field of astronomy has come a long way since the 1982-1984 eclipse. Astronomers around the world will be turning telescopes working at nearly all wavelengths of light to study this curious star system over the next several years. All observations, including visual estimates and all forms of instrumental photometry, are needed, and we hope you'll be among the observers contributing data during that time. It will take a lot of data (yours included!) to remove the cloud of mystery around epsilon Aurigae.

"this strange system..."

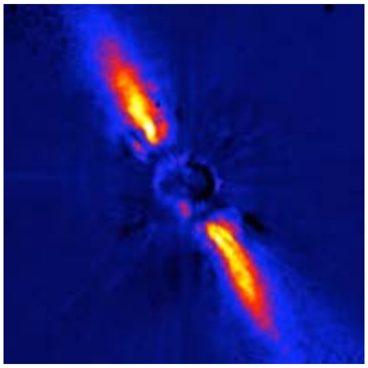
The earliest observational history of epsilon Aurigae is reviewed in Ludendorff's 1904 paper in *Astronomisches Nachrichten*. Johann Fritsch was the first to note the variability of epsilon Aurigae in early 1821, when the star was likely in the midst of a deep eclipse; serious study of this star did not begin for another 20 years. The German astronomers Argelander and Heis both began "regular" observing once every few years around 1842-1843, and the data from both men showed that the star became significantly fainter around 1847. Both then began observing the star in earnest, with several dozen visual magnitude estimates made during the course of that year's dimming. By September of 1848, epsilon Aurigae became significantly brighter again, reaching its near-normal brightness by the end of that year. But the increased observational coverage proved that there were short term variations as well as the long-term dimming both men had observed over the the previous two years. Although they didn't know it at the time, what they had observed was an extremely long-period *eclipsing binary*, and one that was interacting as well.

Hans Ludendorff, former director of the Potsdam Observatory, ca. 1930. Ludendorff published an early, comprehensive analysis of epsilon Aurigae in 1904, suggesting it was an eclipsing binary. (From *Porträtgallerie der Astronomische Gesellschaft, 1931*, courtesy Astrophysikalisches Inst. Potsdam)

Observers later in the 19th Century recorded another dimming event in 1874-1875, and yet another was recorded in 1901-1902. Based on all of the observational evidence to date, Ludendorff suggested the object is similar to the *Algol variables*, now known to be eclipsing binaries that interact when one star transfers matter to the other. In his depiction, the long-term, large variations come from eclipses of one star in the system by the other, while the short-term variations come from the matter flowing from one star to the other. He suggested the period of this star was 54 1/4 years, with the time between the fadings (27.12 years) being the separation of apparently unequal minima. Ludendorff wasn't far from the mark; although the orbital period is now believed to be the lower value of 27.12 years, epsilon Aurigae is indeed a long-period, eclipsing binary. And, though he may not have known it at the time, his closing pronouncement that epsilon Aurigae was a "strange system" would be as true today as it was in 1904.

Lots of models, but no answer

Epsilon Aurigae has been a perplexing puzzle since its discovery, and some of the greatest names in astronomy have tried to understand this system. One major problem was the fact that although the eclipse showed a flat bottom that suggested a total eclipse of the F star, the spectral signature of the F star never disappeared, and there was little sign of the eclipsing object in the spectrum. A 1937 paper by three of the greats of observational astronomy -- Gerard Kuiper, Otto Struve, and Bengt Strömgren, all of the Yerkes Observatory -- suggested the system was an eclipsing binary composed of an F2 star and an extremely cool and tenuous star that they describe as "semitransparent". The F star would be fully eclipsed in their model, but its light would then be scattered by the extremely thin atmosphere of the eclipsing star, like our Sun's corona scatters light from its own photosphere. The 1965 paper by Su-Shu Huang outlined many of the problems with the Kuiper, Struve, & Strömgren model and others like it, and introduced the suggestion of an *edge-on thick disk* as the eclipsing body. Later, Robert Wilson (Wilson 1971) introduced a *tilted, thin disk with a central opening* replacing Huang's thick disk, suggesting that this model could most easily describe all of the observed effects of the eclipses, particularly the mid-eclipse rebrightening.



The infrared disk surrounding the star *beta Pictoris*. Although disks are presumed to exist around all young stars, the presence of a massive disk in the epsilon Aurigae system is mysterious. Did it come from mass transfer off the visible F supergiant? Is it left over from the formation of the entire epsilon Aurigae system, or from the hidden star(s) at the center of the disk? This remains an unanswered question. (Credit: Jean-Luc Beuzit, et al. Grenoble Observatory, European Southern Observatory.)

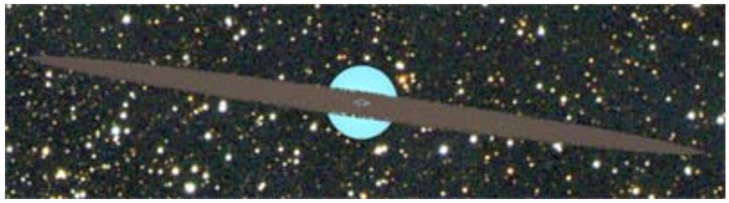
Huang (Huang 1974) and subsequent investigators seem to have converged on the thin disk model as the preferred one. But questions still remain about this system. *Is the F star a massive supergiant or an early post-asymptotic giant branch star? What is at the center of the eclipsing disk? Is the disk tilted or warped? How massive is the disk?* and so on. Some of these questions have reasonable answers now, but there are lots of questions left to be answered about epsilon Aurigae, and these answers may be forthcoming over the next several years.

Epsilon Aurigae: What we think we know

Our understanding of this mysterious variable has grown along with the sophistication of astronomical technology, and while we still don't fully understand the system, we do know a lot more now than we did at the start of the 20th Century. Epsilon Aurigae has been observed in nearly all wavelengths of light; it is known to be bright in the infrared, optical, and ultraviolet, and the star is photometrically and spectroscopically variable at many wavelengths. The primary star has also been resolved using optical interferometry, and has an apparent diameter of about 2.2 milliarcseconds; its absolute size isn't known because there's no reliable distance measure, but it is assumed to be a giant or supergiant star.

In their 1991 paper in *The Astrophysical Journal*, Carroll et al. neatly summarized the state of our understanding at that time:

- the primary is an F0I supergiant, possibly well over 10 solar masses, and is itself *pulsating*,
- the secondary is a cool, thin disk of varying opacity, probably with a hole in the center, and tilted or warped with respect to its orbit about the F star,
- at the center of the disk, there is a hot object -- most likely a massive close binary system rather than a black hole, and
- the combined mass of the disk and central object of the secondary is nearly the same as that of the primary.



One of the possible models for epsilon Aurigae. In this model, a large, opaque disk seen nearly edge-on eclipses the primary star — an F0Ia supergiant. The center of the disk is partly transparent, due to the presence of one or more massive main-sequence stars. Because the disk is seen nearly edge-on to our line of sight, the F0I supergiant isn't completely obscured even at the eclipse minimum. Observations made during the upcoming eclipse may prove and fine-tune this model, or provide evidence for a completely different one. (Background image: a subsection of M38, copyright NOAO, AURA, & NSF.)

Most recent interpretations of the observations seem to confirm the model set forth in 1991. It is now likely that there is an early-type binary system with components having spectral class B5 or earlier at the center of the disk, based upon the ultraviolet spectrum obtained with FUSE (Bennett et al., 2005); the lack of any significant high-energy emission from this system suggests a stellar object rather than a black hole. This would also lend weight to the suggestion that the F star is a post-main sequence massive supergiant rather than a low-mass, early post-AGB star, since early-type B stars have masses several times that of the Sun. This hypothesis also seems reasonable on evolutionary and dynamical grounds (see Eggleton and Pringle 1985 and van Hamme and Willson 1986 for a discussion). Precision photometry of this system by Jeff Hopkins at Hopkins Phoenix Observatory also revealed the presence of low-amplitude semi-regular pulsations in the F star with a quasi-period of about 66 days.

Many observations of this system have been made since the 1982-1984 eclipse; it's important to study the system outside of eclipse to understand the changes that occur during eclipse, and we've developed so many more observational capabilities over the past 20 years that weren't available in 1985. These include space-based observatories like *Spitzer* in the infrared and *FUSE* in the ultraviolet, ground-based optical interferometers, and more widely available optical and infrared photometers (including those of AAVSO observers). As we approach the next eclipse, astronomers around the world will be bringing much more telescopic power to bear on this fascinating system. *Spitzer* and *FUSE* may not be in operation for the upcoming eclipse, but there will be many, many ground-based observatories (and observers like you) watching epsilon Aurigae during 2009-2011.

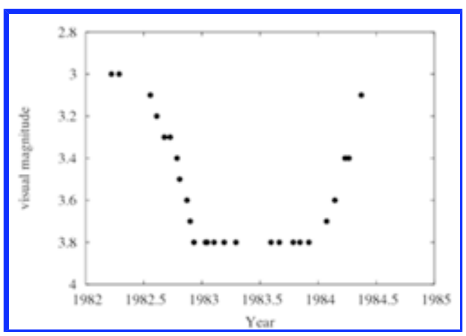
What might we learn from new observations?

The 2009-2011 eclipse of epsilon Aurigae will be very exciting for the astrophysical community, not only because of its rarity, but because so much effort is being devoted to observing this eclipse. Some of the major questions that may be answered are:

- What is the mass of the system and the evolutionary state of the star(s)?
- What is at the center of the disk -- one or more stars or something else?
- What is the geometry of the system, and in particular, is the center of the disk empty or not?
- Will the shape of the light curve in different wavelengths change relative to the 1984-85 eclipse, indicating precession or other physical changes in the inner region of the eclipsing disk?

There's a lot left to study in this star, and a lot of time between now and the eclipse to observe. The eclipse itself won't completely end until the Spring of 2011, and observations after the eclipse will also provide important information about the system. So astronomers are going to be concentrating on this object for *the next three years* at least! Although not everyone will spend all of that time observing epsilon Aurigae, even a few well-timed observations here and there will be helpful.

Everyone has something to contribute to this campaign. Visual observers have contributed observations of all eclipses since 1928. We hope that everyone can go and observe this object in 2009 -- since it's a naked-eye star, it will be within reach of all of our observers. At your next observing session, try making a visual estimate of epsilon Aurigae, regardless of whether you're a visual or CCD observer -- it's so bright, even a naked-eye estimate is possible, and with a modest-sized telescope *even daytime observations are possible!*



Visual observations of the 1982-1984 eclipse (G. Samolyk). The eclipse is flat-bottomed which typically indicates a total eclipse, but the light from the F star being eclipsed is present in the spectrum throughout the event, and the secondary object emits very little light of its own. It is believed that the eclipsing secondary is a disk seen nearly edge-on, and that the F star is not fully eclipsed. *Click image to enlarge.*

Those of you with instrumental photometers (CCD and PEP) can also make important contributions to this campaign. One major way is to study the pulsations in the F star, a low-amplitude irregular variable. Robert Stencel notes on his epsilon Aurigae campaign page that models for the inner disk can be refined by following the pulsations through the eclipse; it might be possible to tell how large the central opening in the disk is by measuring how much the mid-eclipse brightening is and comparing it with the pulsation phase. PEP observers are those best prepared to study this object with the precision required, and we've recently released a new PEP chart specifically for this campaign.

Those of you performing spectroscopy can also make interesting observations. As this 2007 paper by L. Schanne shows, small telescopes with spectrographs are capable of measuring significant changes in the spectrum of this star, and in this case at least, these changes aren't fully understood. Similar observations could easily be made leading up to and during the eclipse and might reveal new information useful for understanding the system.

The epsilon Aurigae campaign

There is a lot of interest in epsilon Aurigae right now, and its been chosen as one of the key projects for the upcoming International Year of Astronomy (IYA) celebration in 2009. Because it's such a bright star, even modest equipment (including the naked eye) can provide useful information, and it will be a great way to show how everyone can contribute to scientific research. The AAVSO will be putting out more information on epsilon Aurigae as the eclipse draws near, but there are two websites of interest right now by friends of the AAVSO: one by Jeff Hopkins and another by Robert Stencel. Stencel and Hopkins were key organizers for the 1982-4 eclipse campaign, and are continuing their comprehensive study of this mysterious binary today. Their websites give some background on this fascinating star, and look toward what we hope to learn from observations.

Even though the start of the eclipse is still over a year away, observations are needed **now**. We need to have good look at what epsilon Aurigae is doing outside of eclipse to understand what changes occur during the eclipse. This is a campaign that *everyone* can participate in at some level, from occasional visual estimates throughout the eclipse to intensive, high-precision photometry. Even more importantly, it's a great opportunity for experienced variable star observers to share their knowledge and experience with others. A major part of **IYA 2009** is educating the general public about astronomy, and one of the best ways to teach is to have people participate in research! Talk about epsilon Aurigae at star parties, schools, and public nights at your observatory. Encourage non-VSO'ers in your astronomy clubs to try observing. You might spark a new passion for observing in your audience by sharing what you know about this unique -- and still mysterious -- variable star.

For more information

- A-scale chart of Epsilon Aurigae, from VSP
- PEP Chart for Epsilon Aurigae
- Information pages: Jeff Hopkins' site and Robert Stencel's site
- The AAVSO's contribution to IYA 2009
- Reviews of epsilon Aurigae: Guinan and DeWarf 2002 and Carroll et al. 1991
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- The Photoelectric Photometry (PEP) Program of the AAVSO
- The Infrared Photoelectric Photometry Program of the AAVSO

This Variable Star Of The Season article was prepared by Matthew Templeton, with assistance from Jeff Hopkins and Robert Stencel.

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