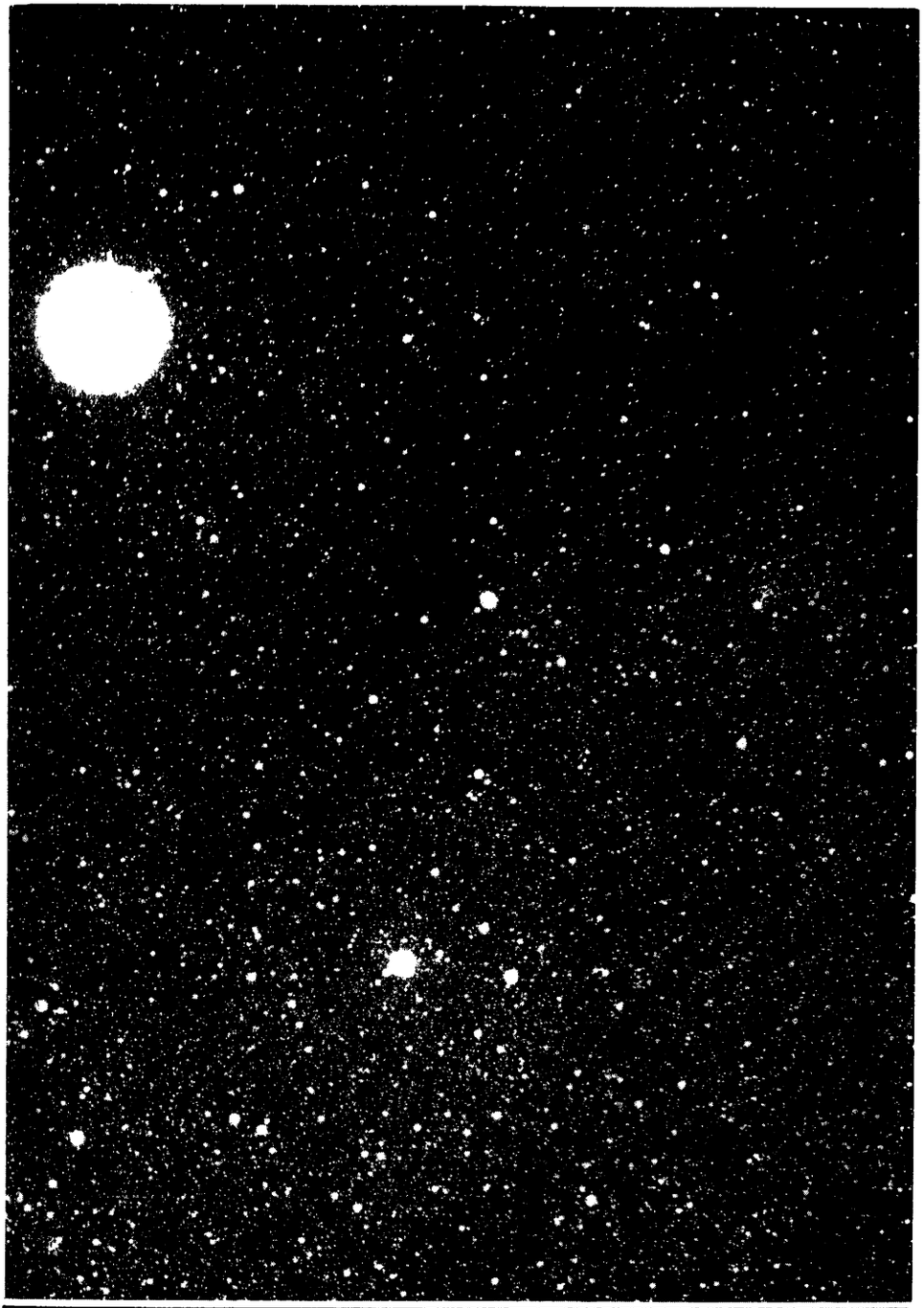
DESCRIPTIVE NOTES (Cont'd)

14th magnitude, discovered by E.Barnard in 1901, when the separation was 12.6" in PA 181°. The most recent observations of this star, reported in the Lick "Index Catalogue", show no change in separation, but a slight decrease in the PA to about 174°. The measures suggest common proper motion with the primary, and give the luminosity of the faint star as about 1/630 that of the Sun. The projected separation of the pair is about 350 AU.

EPSILON Mag 3.00 (variable); Spectrum about F0, but given by various authorities as A8, F0, or F2. Supergiant, luminosity class Ia. Position 04584n4345. This is one of three stars forming the flattened triangular group called "the Kids"; the other two are Eta and Zeta. Epsilon is the northernmost of the three, and the nearest to Capella. It is located about 3° distant from Capella, toward the southwest.

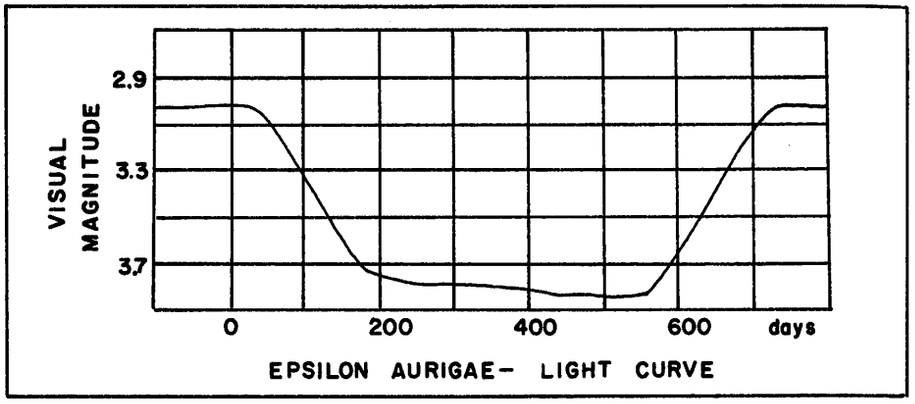
Epsilon Aurigae is a noted eclipsing binary star, one of the most remarkable and puzzling of all known eclipsing variables. It has been the subject of so many studies and investigations that O.Struve (1962) declared its history to be "in many respects the history of astrophysics since the beginning of the 20th century." Ironically, the chief result of this intensive research has been the gradual elimination - one after the other - of the seemingly best and most promising interpretations of the system. It cannot be said that our present understanding of Epsilon Aurigae is very clear, but it is probably safe to say that there is some major error in the interpretation which requires one of the components to be vastly larger than any other star known.

The observed facts about the system are quickly given. The two stars revolve about their common center of gravity in the exceptionally long period of 9883 days, or 27.06 years. In the course of each revolution the visible star is eclipsed by an unseen companion, and the apparent magnitude of Epsilon then falls from 3.0 to 3.8. The Moscow General Catalogue of Variable Stars (1958) gives the photographic range as 3.73 to 4.53. The deepest phase of the eclipse lasts for a full year; the partial phases last half a year each. The beginning of the eclipse can be detected about 190 days before greatest obscuration is reached.



THE KIDS. Epsilon Aurigae is at center; Eta and Zeta are the two stars near the bottom. Capella is the bright star at upper left. Lowell Observatory 5-inch camera plate.

DESCRIPTIVE NOTES (Cont'd)



EPSILON AURIGAE- LIGHT CURVE

During minimum, the light is usually said to remain nearly constant, but observations at the most recent eclipse, in 1955-1957, showed a slight fading of about 1/10 magnitude between second and third contacts. The cause of this is not known. There are also slight secondary irregularities of about the same order of magnitude which become noticeable during an eclipse, and for several years before and after. At the 1928 eclipse, some of these irregularities seemed to repeat at intervals of about 11 months, though other observations have revealed no real evidence of true periodicity.

As an eclipsing binary, Epsilon Aurigae is an interesting example of a type in which a long "atmospheric eclipse" precedes and follows the actual hiding of the star by its companion. Thus it may be that the secondary fluctuations are due to large-scale irregularities in the outer atmosphere of the eclipsing star. Other well known stars of this class are VV Cephei, Zeta Aurigae, and 31 Cygni.

The first recorded minimum of Epsilon Aurigae was that of 1821, observed by K.Fritsch. At the next eclipse, in 1847-1848 the variability was confirmed by Schmidt, Heis, and Argelander. Schmidt continued his observations, and recorded a third minimum in 1874-1875. In 1912 an analysis of the accumulated observations was published by H.Ludendorff, it being then evident that the star was an eclipsing binary of unusually long period and extraordinary interest. Although the eclipses of 1928-1930 and 1955-1957 were very widely observed, the main problem remains unsolved: What is the true nature of the mysterious companion which causes

DESCRIPTIVE NOTES (Cont'd)

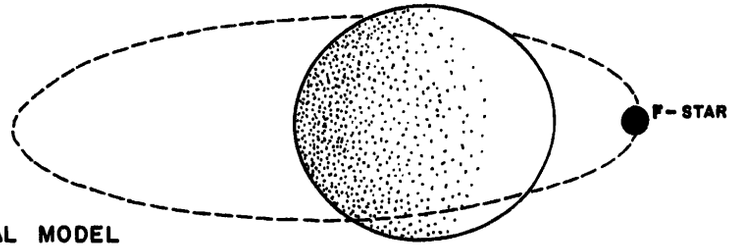
the eclipses, and which by some calculations may be the largest star known ?

THE BRIGHT COMPONENT, which gives all the visible light of the system, is a supergiant whose type is close to F0; the spectral characteristics suggest a luminosity which probably equals that of Rigel, at about 60,000 times the light of the Sun. The computed absolute magnitude is about -7.1. The diameter may be about 180 times that of the Sun. From these figures, the estimated distance is about 3300 light years, too great for reliable parallax measurements. An attempt made at Allegheny, however, yielded a result of 0.001", equivalent to 3260 light years. Needless to say, such a result cannot be taken at face value, and proves only that the distance is very great. The annual proper motion of the star is less than 0.01"; the radial velocity averages about 1.8 miles per second in approach.

From the radial velocity measurements, the mean orbital speed of the visible star is in the range of 9 to 10 miles per second, and the orbit is found to be considerably non-circular, with an eccentricity of about 0.33. The orbit is about 15 AU in radius, or about 1.4 billion miles. Very similar results were obtained by Dr.K.Strand (1959) by astrometric measurements of Yerkes 40-inch telescope plates; he obtained a semi-major axis of 0.014", corresponding to about 1.25 billion miles or 14 AU. The orbit of the star seems to be oriented about 18° from the edge-on position. The total mass of the system is believed to be about 30 solar masses, with the visible star having somewhat the greater mass. The 27-year period then implies a mean separation of about 30 AU, comparable to Neptune and the Sun.

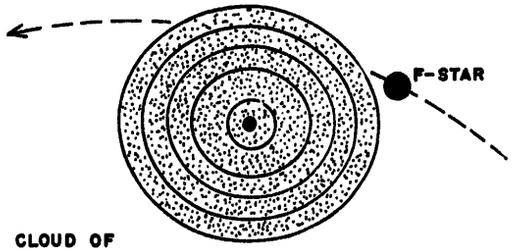
THE ECLIPSING COMPONENT has never been observed directly or detected spectroscopically, and would have remained entirely unknown except for its periodic transits across the bright primary. According to the usual or "traditional" interpretation, first introduced in 1937 by G.Kuiper, B. Stromgren, and O.Struve, the star may be a low density supergiant of exceptional characteristics, perhaps the largest, coolest, and most rarified star known. It would be 15 times the size of its companion, or about 2800 times the diameter of the Sun. The average density, about one-billionth that of the Sun, would approach what we would call an absolute vacuum. According to this interpretation,

DESCRIPTIVE NOTES (Cont'd)



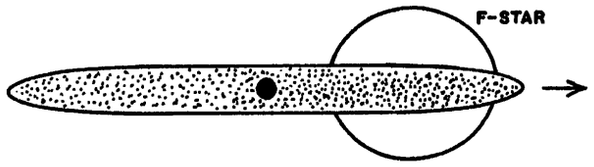
TRADITIONAL MODEL

F-STAR IS ECLIPSED BY SUPERGIANT INFRARED STAR WHOSE DIAMETER MAY BE OVER 2500 TIMES THE SIZE OF THE SUN.



SHELL MODEL

ECLIPSING BODY IS A CLOUD OF GASES AND SOLID PARTICLES SURROUNDING A SMALL COMPANION STAR



TRANSIT MODEL

ECLIPSING BODY IS A FLATTENED RING WHICH IS SEEN EDGE-ON DURING ITS TRANSIT OF THE F-STAR. THERE ARE NO TOTAL ECLIPSES.

POSSIBLE MODELS FOR THE PECULIAR SYSTEM EPSILON AURIGAE.

DESCRIPTIVE NOTES (Cont'd)

the eclipsing star is normally invisible, partly because its faint light would be lost in the glare of the highly luminous primary, but also perhaps because it may be at too low a temperature to emit much visible radiation. A surface temperature of less than 1500° K has been obtained through indirect calculation, and indicates that the star radiates chiefly in the far infrared, emitting virtually no visible light.

Still following this interpretation, we find another peculiarity: the star seems to be partially transparent, at least in the outer layers. This is made evident by the fact that the visible star does not disappear completely when eclipsed; it merely dims to about half its normal light. And, although the shape of the light curve seems to imply a total eclipse, the spectrum of the eclipsed star remains visible throughout "totality"and is essentially unchanged except for a definite strengthening of the absorption lines. A doubling of the lines, before and after eclipse, has been observed, and may be attributed to gas streams between the components. A more difficult feature to explain is the fact that the eclipsed star fades without changing color; the eclipsing body apparently acts as a "neutral filter" and absorbs all wavelengths equally. To explain this feature, and also the nearly constant light during maximum eclipse, it has been proposed that the outer layers of the eclipsing star are ionized by radiation from the F-star, and the actual eclipsing body is this relatively thin ionized layer. This is the model presented in the first diagram on the opposite page.

If it is actually a star, this strange object may well be the largest star known, and would fill up much of the Solar System out to beyond the orbit of Saturn. Other interpretations have been suggested, however, and at present it seems likely that our ideas about this strange system will soon be drastically revised. All attempts to detect the infrared radiation of the strange companion have failed, and it now seems more likely that the eclipsing body is not a star at all, but rather a vast cloud of gases, dust, or solid particles, surrounding a relatively small star which cannot itself be detected. M.Hack (1961) has proposed that the eclipsing body is a shell or ring of ionized gases surrounding a hot O-type or B-type star which may be about

DESCRIPTIVE NOTES (Cont'd)

2 magnitudes fainter than the primary, and is therefore undetectable spectroscopically. S.Huang (1965) suggests that the secondary star is encircled by a flattened disc of rotating gases which is viewed edge-on, and which passes horizontally across the primary star to produce the eclipses. According to this model, shown in the third of the diagrams on page 270, the nearly flat bottom of the light curve does not imply that the eclipse is total, and there is thus no need to explain why the eclipsed star is still visible all through "totality". With these newer interpretations, we may be near a solution of the mystery of Epsilon Aurigae, though at the cost of demoting this remarkable object from its ranking position among the largest known stars.

Epsilon Aurigae also has a faint visual companion of magnitude 14, discovered by S.W.Burnham with the 18½-inch refractor at Dearborn Observatory in 1891. According to the Yale "Catalogue of Bright Stars" (1964) the two stars probably form a physical pair. The projected separation is about 30,000 AU, or close to 0.5 light year. (Present apparent separation about 28.6")

ECLIPSE TIME-TABLE for EPSILON AURIGAE

A	June 9, 1928	July 1, 1955	July 22, 1982
B	Nov 30, 1928	Dec 21, 1955	Jan 11, 1983
C	May 30, 1929	June 20,1956	July 12, 1983
D	Dec 4, 1929	Dec 25, 1956	Jan 16, 1984
E	May 14, 1930	June 4, 1957	June 25, 1984

A = partial phase begins B = "total" phase begins
C = mid-eclipse D = total phase ends
E = partial phase ends

ZETA Name- SADATONI. Mag 3.76 (variable); spectrum K4 II + B7 V. Position 04590n4100. One of the three stars forming the small triangular group called "the Kids", located about 2.75° south of Epsilon Aurigae. It is an eclipsing variable, first recognized as a spectroscopic double by A.Maury in 1897, and confirmed as a binary by W.W.Campbell in 1908. Zeta Aurigae consists of a relatively small blue-hot star and a K-type giant companion,

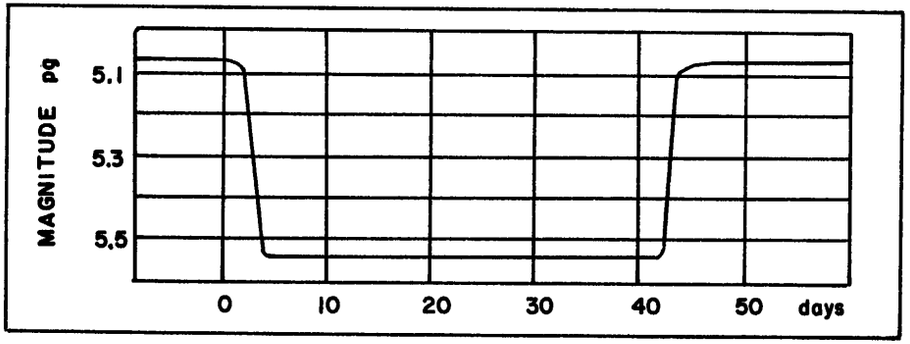
DESCRIPTIVE NOTES (Cont'd)

orbiting about their common center of gravity in a period of 972.176 days, or about 2.66 years. The computed separation of the components is in the range of about 500 million miles, and the eccentricity of the orbit is 0.40. The main facts about the two stars are given in the table below.

	Spect.	Diam.	Mass	Lum.	Abs.Mag.	Temp.
A	K4 II	160	8.3	2100	-3.5	3200° K
B	B7 V	4	6.8	400	-1.6	15000

The diameter and luminosity of the primary are perhaps the most uncertain figures in the table. A few authorities have classed the star as a supergiant of class Ib, which could raise the absolute magnitude to as high as -4.4. The diameter of 160 X ⊙ should be regarded as a minimum; some estimates have ranged up to 300 solar diameters. The mass figures are according to recent studies (1960). From the derived luminosities the distance of the system appears to be about 1200 light years. The annual proper motion is about 0.03"; the radial velocity is 8 miles per second in recession.

The eclipse of the smaller B7 star by its giant companion occurs once every 2 years and 8 months. For a period of about a month before the actual eclipse begins, the light of the small star must come through progressively deeper layers of the giant's atmosphere, and spectroscopic study at this time has revealed much information about the structure and composition of the star's atmospheric layers. There appear to be local condensations and irregularities in the giant's chromosphere, perhaps comparable to solar



ZETA AURIGAE– PHOTOGRAPHIC LIGHT CURVE