Variable Star Of The Month

October, 2002: Mu Cephei
2140+58

Mu Cephei - A Most Beautiful Object

The bright yellowish star at the top of the emission nebula IC 1396 is Mu Cephei, a red supergiant with a diameter the size of Saturn's orbit!
Credit: Matt BenDaniel

The star of the month this month is the famous, interesting and extremely bright red supergiant in the constellation Cepheus, Mu Cephei. This star may be the largest star visible to the naked eye - it is roughly 2.4 billion miles across! If it replaced our Sun, it would extend beyond the orbit of Saturn. Mu Cep is a slow semiregular variable that is easily visible to the unaided eye in suburban skies when at its maximum brightness of magnitude 3.4, but may be a little more challenging at its minimum of 5.1. The color of the star is quite magnificent and has been the source of some discussion. It is most often described as "a deep red" or "reddish orange" but has sometimes been noted as "orange" and even having "a purplish tint". The most famous observation of Mu Cep comes from Sir William Hershel who commented on its "garnet" color, an observation that lead to the popular name "Herschel's garnet star". William Herschel (1738-1822) was probably the most famous astronomer of the 18th century. He discovered the planet Uranus, many new nebulae, clusters of stars and binary stars, and was the first person to correctly describe the form of our Galaxy, The Milky Way. While writing about the proper motions of the Sun and Solar System in 1783, Herscel noted some stars not listed in Flamstead's well-known star catalogue -- one of which was the bright Mu Cephei. Herschel's "garnet star observation" can be found in the *Philosophical transactions of the Royal Astronomical Society of London* (1783), in the section called, "Stars newly come to be visible" on page 257 William Herschel writes:

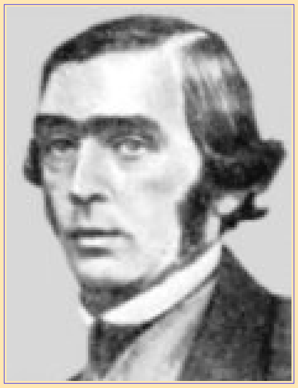
Sir William Herschel (1738 - 1822) dubbed Mu Cephei, the "garnet star" in 1783.

> A very considerable star, not marked by Flamstead, will be found near the head of Cepheus. Its right ascension in time, is about 2'19" preceding Flamstead's 10th Cephei, and it is about 2º20'3" more south than the same star. It is of a very fine deep garnet colour, such as the periodical star o ceti was formerly, and a most beautiful object, especially if we look for some time at a white star before we turn our telescope to it, such as α cephei, which is near at hand.

Another interesting remark by Hershel appears at the end of his comments on new and changed stars. On page 258 he writes:

> Here we ought to observe, that it is not easy to prove a star to be newly come; for though it should not be contained in any catalogue whatsoever, yet the argument for its former non-appearance, which is taken from its not having been observed, is only so far to be regarded as it can be made probable, or almost certain, that a

> star would have been observed had it been visible. For these reasons I will lay no particular stress on the new appearance of the above stars; they are, however, such as do well deserve to have their places settled, while I shall leave it to others to determine how far they may think them to be new visitors to those starry regions that fall within the reach of our sight.



Astronomer John Russel Hind discovered the variability of Mu Cephei in 1848

Herschel was correct in doubting that he was the first to observe this star. In the 1600s Johann Bayer, who used the Greek alphabet to name the brighter stars in each constellation, gave the star its name, Mu Cephei. One would think that given the brightness and color of this star that it would be a popular target among observers throughout the years. Indeed, in 1848, John Russel Hind of the Royal Astronomical Society discovered that this "garnet star" was a variable star, one that changes in brightness (A.N. 658). J. R. Hind was the son of a lace manufacturer, who worked at various observatories before working for the Nautical Almanac. He left school at age 17, and later became known as a famous asteroid hunter and was credited with having discovered 11 minor planets, Nova Ophiuchi 1848 and R Lep (also known as Hind's Crimson Star). At a BAA variable star section meeting, Dr. Alan Chapman noted that Hind never truly felt a part of the astronomical community, as in 1851 when he was elected a fellow of the Royal Astronomical Society but did not turn up to sign the book, which was a requirement of receiving the award. Later, when he was elected a second time, he did turn up to sign the book (BAA Webpage). In 1853 Hind was awarded the Gold Medal from the Royal Astronomical Society.

The Big Picture

Mu Cephei is really big. It is so big that it is one of the largest stars known; estimated to be the third largest star in the sky after its neighbor VV Cephei and the even larger Epsilon Aurigae (both are eclipsing binaries). If you were so inclined, you could fit one billion suns inside mu cephei and have room to spare. It is three times as large as Mira (omi ceti) and much more luminous than the sun. A star of this grandeur deserves no other name than that of supergiant. It is a red supergiant that probably started its life at a substantial 20 to 25 solar masses (a high mass star is considered to be 10 solar masses or more) and has evolved "quickly" (high mass stars burn energy faster than lower mass stars). The life expectancy of a star like Mu Cephei is only around a few million years - short for astronomical time scales.

The Crab Nebula from VLT shown here is what remains of a supernova explosion that occurred in 1054 AD.

The evolution of Mu Cephei is probably similar to other high mass stars which Kaler (1997) explains in the following way. It starts by burning hydrogen in its core until there is no more left, it then expands to its current supergiant status. Now helium burning takes place in the core while hydrogen burning continues in the outer shells. Since it is so big, the gravitational energy on the core is great and further nuclear burning can take place. Carbon will be burned to form magnesium then magnesium to silicon and finally silicon to iron. Iron is the end of the road, however, and no energy can be generated by additional fusion. Once the iron core develops, fusion stops. The outward push of hot gases from the interior can no longer counteract the inward pull of gravity so gravity wins. The core collapses, releasing a vast amount of energy in a few seconds. As the core collapses, it first rebounds, sending a shock wave out into the surrounding envelope. The shock wave and a huge number of nearly massless particles called neutrinos push the envelope outward, creating a cataclysmic explosion - a supernova - that can be seen across vast reaches of the universe. The iron atoms break down ultimately to protons and electrons, which merge, producing a ball of neutrons that squeezes to 30 kilometers across: called a neutron star. This is the predicted future of Mu Cephei, it will eventually explode in a huge supernova explosion leaving a supernova remnant with a neutron star or a black hole (Kaler 1997).

Really Cool Stars

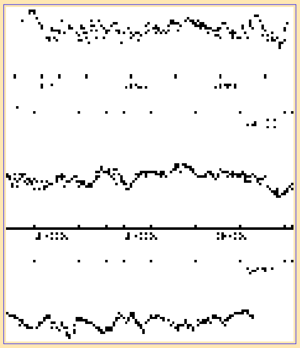
Mu Cephei has not quite reached the point of a supernova explosion, although it may be close. Mu Cep has expanded and cooled and is currently in its red supergiant phase of life. Like other red giants and supergiants, it is unstable and it pulsates. Right now the radial (in-and-out) pulsations are of a small-amplitude (about 1.67 mag), but eventually it will probably pulsate with a large-amplitude. Small amplitude red variables (SARVs), like Mu Cephei, are defined as giants or supergiants that are pulsating with a small-amplitude (up to 2.5 mag) and with time scales of 20-200 days or more. The term "SARV" was originally used by the late Olin Eggen who spent several years surveying, studying, and classifying these stars. In a series of papers he defined small-, medium- and large- amplitude red variables (SARVs, MARVs and LARVs), and even a group of ultra small-amplitude variables which he called "Sigma Librae Stars". The "official" classification scheme of the GCVS divides pulsating red giants into semi-regular (SR) variables with either "persistent periodicity" (SRa) or "poorly expressed periodicity" (SRb); there are also the very luminous (SRc) and the slow irregulars (L). Pulsating red supergiants that show semiregular brightness variations are classified as SRc or Lc. Mu Cephei is one of these and is listed in the General Catalogue of Variable Stars (GCVS) as a semiregular supergiant variable (type SRc) with a spectral type of M2eIa, a visual range of 3.43 - 5.1, and periods of 730 and 4400 days.

The pulsations in Mu Cep, although relatively small, have driven off the outer parts of the star, producing a shell of dust and gas around this variable. One interesting observation is that there are water vapor bands found in emission in the spectrum of Mu Cep. Although the presence of water has been known in the stellar environment since the 1960s, the recent *Infrared Space Observatory (ISO)* mission has explored it in full detail. Some important results are that water has been found to exist everywhere in the universe including the stars. Tsuji (2000) have confirmed that the early M supergiant star, Mu Cep is actually surrounded by a huge optically thick sphere of warm water vapor. This provides a new clue to understanding the nature of water in the stellar environment and invites more research to be done in this area.

But what causes the pulsations of Mu Cep? Dr. John Percy in his excellent VSOTM article called, "EU Delphini and the Small Amplitude Pulsating Red Giants" explains the pulsation mechanism. He writes that the "pulsation is 'driven' by the same process that drives other kinds of pulsating stars -- the 'heat engine' effect of ionization of hydrogen and helium. As the pulsating star contracts, these elements absorb radiation and become ionized. As the star expands, this ionization energy is released, giving an outward 'push' which keeps the pulsation going -- just as a carefully-timed push on a playground swing keeps the occupant swinging, happily."

Dr. Percy also talks about the possibilities of more than one pulsation period for a star. Any object, whether the air in a bugle or the gas in a star, can vibrate in various "modes" or harmonics. A skilled musician can make the air in a bugle vibrate in a series of harmonics, producing the familiar notes of a bugle call. Likewise, stars can pulsate in different modes, either at different times, or at the same time. Mattei et al. (1997) and later, Kiss et al. (1999) analyzed AAVSO visual measurements of larger-amplitude red giants, and found that many of them had two periods with a ratio of about 2:1. Multiperiodicity could explain some of the irregularity of these stars. Several red giants in the AAVSO visual and photoelectric programs appear to pulsate in different modes at different times. What causes this is not understood. Nor is the cause of the long-term variations in the brightness of these stars.

The Light Curve



The 85-year AAVSO light curve of Mu Cephei from 1917 to 2002. Each point is a 10-day mean. Click image to enlarge.

In a star like Mu Cephei, where the variations are slow and complex, present observations can give only a snapshot of its behavior. Nevertheless, the coverage of this star has been excellent and is almost complete from 1881 onwards, thanks largely to an epic 55-year run of 5275 observations by the German visual observer Joseph Plassmann. The AAVSO observer Ed Oravec has also been an avid observer of this star - he has contributed 1,790 observations of the star from 1945 to the present. Such a long continuous run of observations by a single person has been particularly valuable to later researchers because it is largely free from the observer-dependent errors that normally plague visual observations of red stars. As a consequence, Plassman's data has been central to practically all subsequent studies of the periodicity of this star.

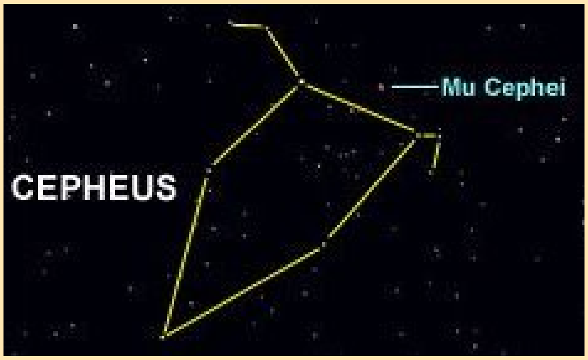
Brelstaff et al. (1997) have determined the presence of two coherent periods at about 850 and 4400 days, which are consistent with those seen in earlier data. It further suggests that the other short periods around 730 days, as given by the GCVS, and 920 days are artefacts produced by distortion of the 850-day period.

The AAVSO has about 35,000 observations of Mu Cephei in the AAVSO International Database from 1917 to 2002. This is good coverage of the star, but as Brian Skiff (2001) points out in his article, "Historical Archive Photometry of μ Cephei" there are historical observations that do not currently exist in databases that provide important information about some stars. Skiff stresses the need to make data available that may be 'hidden'in obscure journals and observatory publications that are most likely no longer being published at all. He uses Mu Cephei as an example of what can be learned by making public some historical data - he posts historical observations of Mu Cep to an ftp site for the public to use.

Observing Mu Cephei

Wouldn't you like to help keep the coverage of this star complete? Mu Cep is a relatively easy-to-find variable star located in the jaw area of Cepheus, the King. You can locate it with the naked eye or, in really bad light pollution by working toward it from Alpha with a finderscope. There is an 'a' scale AAVSO Chart for delta cep that has the location of Mu Cep on it.

"According to some observers" writes Burnham, "the star varies in color as well as in light. It usually appears a deep orange-red but on occasion seems to take on a peculiar purple tint.



Mu Cep is located in the constellation Cepheus.

Since human eyes vary in color sensitivity, and since color is affected by atmospheric and instrumental factors, it is still uncertain whether such changes are real." In particular a star's color tends to be most vivid in a small telescope, assuming the aperture is large enough to collect the light necessary for color to be perceived at all. So, in order to fully realize the peculiar tint of the "Garnet Star", use a small telescope or binoculars and take Herschel's advice by comparing the light with a white star such as Alpha Cephei at the time.

A Note About Color:

Dr. Philip Steffey points out that the color of Mu Cep will most likely NOT appear red to the naked eye. He states, "The only way Mu Cep can appear red to the naked eye is due to extreme chromatic scintillations. In ordinary binoculars, which boost the star's apparent magnitude to -0.5 to +1, the color at medium altitudes is yellowish orange, roughly 30% saturated, similar to that exhibited in the first picture of this article. Large binoculars and telescopes yield a more yellow and paler color. The steady naked-eye color is brown--degenerate yellowish orange, for the illuminance factor is under 9--very dark gray to soft black on a daytime grayscale. These colors agree with subphotopic model predictions I'm developing."

He continues, "W. Herschel's 'garnet' comparison was unfortunate, for many succeeding observers have mindlessly accepted this as meaning red or reddish orange. Actually, garnets come in 19 hues including blue, yellow, and green. Are we certain about the variety Herschel meant? And was he reporting naked-eye or optically aided observations? If the latter, he may have been fooled by chromatic aberration produced by nonachromatic eyepieces."

For more information on the colors of stars - including common misconceptions - consult the article, "The Truth About Star Colors", by Philip Steffey in *Sky and Telescope*, September, 1992, p. 266.

Herschel compared the light of Mu Cephei to that of a garnet stone - but there are many different types of garnet stone - which one do you think he meant? What color does Mu Cep look like to you?

When observing variables which have a red color like Mu Cep, it is recommended that the estimate be made by the so-called ”quick glance” method rather than by prolonged “stares.” Due to the *Purkinje effect*, red stars tend to excite the retina of the eye when watched for an extended period of time; accordingly, red stars would appear to become unduly bright in comparison to blue stars, thus producing an erroneous impression of the relative magnitudes.

Another technique that is strongly recommended for making magnitude estimates of red stars, is called the “out-of-focus method.” That is, the eyepiece must be drawn out of focus so far that the stars become visible as colorless disks. In this way a systematic error due to the Purkinje effect is avoided. If the color of the variable is visible even when the stars are out-of-focus, you may need to use a smaller telescope or an aperture mask.

To help you make your observation there is an AAVSO PEP chart available with comparison star magnitudes marked. Mu Cephei shows long-term large amplitude and short term small amplitude variations. The large amplitudes could be detected by visual observing. However small amplitudes, of less than one magnitude, need a higher precision - thus its entry into the photoelectric photometry program. The AAVSO photoelectric photometry (PEP) program was established in the early 1980s to observe the few dozen stars where the variations were too small to be observed effectively by visual techniques. Now, almost two decades later, the AAVSO has one of the largest and longest database of photometry of bright, pulsating red giants, consisting of over 50 such stars.

There is still a lot to be learned about pulsating red giants and supergiants. AAVSO photoelectric observers monitor these "SARVs" every few nights, and have done so for a decade or more, uncovering new insights about the last stages of the lives of stars like our own.

For more information about the AAVSO Photoelectric Photometry Committee and the stars contained in the program, be sure to visit the committee web pages.

In the Neighborhood

The Elephant's Trunk in IC1396
In this close-up telescopic view, The Elephant's trunk nebula winds through the emission nebula and star cluster complex IC1396 Credit:Robert Gendler

The whole region surrounding the famous red variable star Mu Cephei is a very pretty sight in a wide field telescope. At the center is the striking triple star system Struve 2816, and nearby is the double system Struve 2819. But there is more. If you are fortunate enough to have very dark skies, you will be able to see the big dim open cluster IC 1396 and the large diffuse emission nebula that engulfs the cluster and has the same name, IC 1396. As James Mullaney in a *Sky and Telescope* article describes it, "The huge nebulous expanse demands a very dark, transparent night and fully dark-adapted eyes. Careful sweeping back and forth across the nebula's position should reveal a faint gossamer glow - it can be seen even in a 3-inch scope at 30x. Various observers have described the nebula as a 'large haze' and 'like a very faint Rosette Nebula.' Referring to the combined cluster and nebula, one sightseer went so far as to call it a 'magnificent object'. The view of this entire amazing region of sky through the eyepiece of a rich-field telescope leaves no doubt that this is indeed an apt assessment (Mullaney, 1999)."

We hope that you do get a chance to observe the beautiful variable Mu Cep. And keep in mind what William Tyler Olcott writes in his book *Star Lore of All Ages*, "... and the star mu cephei is worth observing as being Sir William Herschel's celebrated 'Garnet Star,' one of the reddest stars in the sky, and a fine object in an opera-glass (Olcott, 1911)."

For More Information

- Brelstaff, T.; Lloyd, C.; Markham, T.; McAdam, D. "The Periods of Mu Cephei" *Journal of the British Astronomical Association*, **107**, 135-140, 1997.
- Burnham, Robert Jr. *"Burnham's Celestial Handbook"*, Volume 1, 596-597, Dover Publications, New York, 1966.
- Chapman, Allen BAA Variable Star Weekend Meeting at Alston Hall, Preston "A History of Variable Star Astronomy by Dr Allan Chapman"
- Herschel, William, Sir. "On the proper motion of the sun and solar system; with an account of several changes that have happened among the fixed stars since the time of Mr. Flamstead" *Philosophical Transactions of the Royal Society of London*, **73**, 247 - 283, London, 1783.

- Kaler, J.B. "Extreme Stars" *Astronomy*, **25**, 54-59, 1997.
- Kiss, L.L., Szatmary, K., Cadmus Jr., R.R., & Mattei, J.A. "Multiperiodicity in semiregular variables. I. General properties" *Astronomy and Astrophysics*, **346**, 542, 1999.
- Mattei, J.; Foster, G.; Hurwitz, L.; Malatesta, K.; Willson, L. and Mennessier, M. "Classification of Red Variables" *Proceedings of the ESA Symposium 'Hipparcos - Venice '97', 13-16 May, Venice, Italy, ESA SP-402*, July, 1997.
- Mullaney, James. "Celestial Spectacular in Cepheus", *Sky and Telescope*, 124-129, November, 1999.
- Olcott, William Tyler *Star Lore of All Ages* G.P. Putnam's Sons, The Knickerbocker Press, New York, 1911.
- Percy, John R.; Desjardins, A.; and Yu, Lawrence. "Small-Amplitude Red Variables in the AAVSO Photoelectric Program: Light Curves and Periods" *Publications of the Astronomical Society of the Pacific*, **108**, 139-145, February, 1996.
- Skiff, Brian A. "Historical Archive Photometry of μ Cephei" *Information Bulletin on Variable Stars*, 5015, 2001.
- Tsuji, Takashi. "Water in Emission in the *Infrared Space Observatory* Spectrum of the Early M Supergiant Star μ Cephei" *The Astrophysical Journal*, **540**, Issue 2, pp. L99 - L102, 2000.
- Variable Star of the Month, July 2001, EU Delphini and the Small-Amplitude Pulsating Red Giants, by John Percy.
- "Mu Cephei: Betelgeuse's Big Sister" *Sky and Telescope*, **70**, 30, 1985.
- "Three Cepheus Variables" *Sky and Telescope*, **82**, 396-398, October, 1991.

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

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