Carbon Stars: Reddest of the Red

Stars with carbon-rich atmospheres are the most deeply colored ones you can see. | **By Brian A. Skiff**

About 10 years ago the Canadian comet discoverer Rolf Meier and his wife, Linda, stopped by Lowell Observatory in Flagstaff, Arizona, where I work. I showed them the cool supergiant variable star S Persei, whose light I was measuring with a photometer on the observatory's 21-inch telescope. Linda looked at the star in the photometer's viewing eyepiece and exclaimed, "Oh! It's *very* red!"

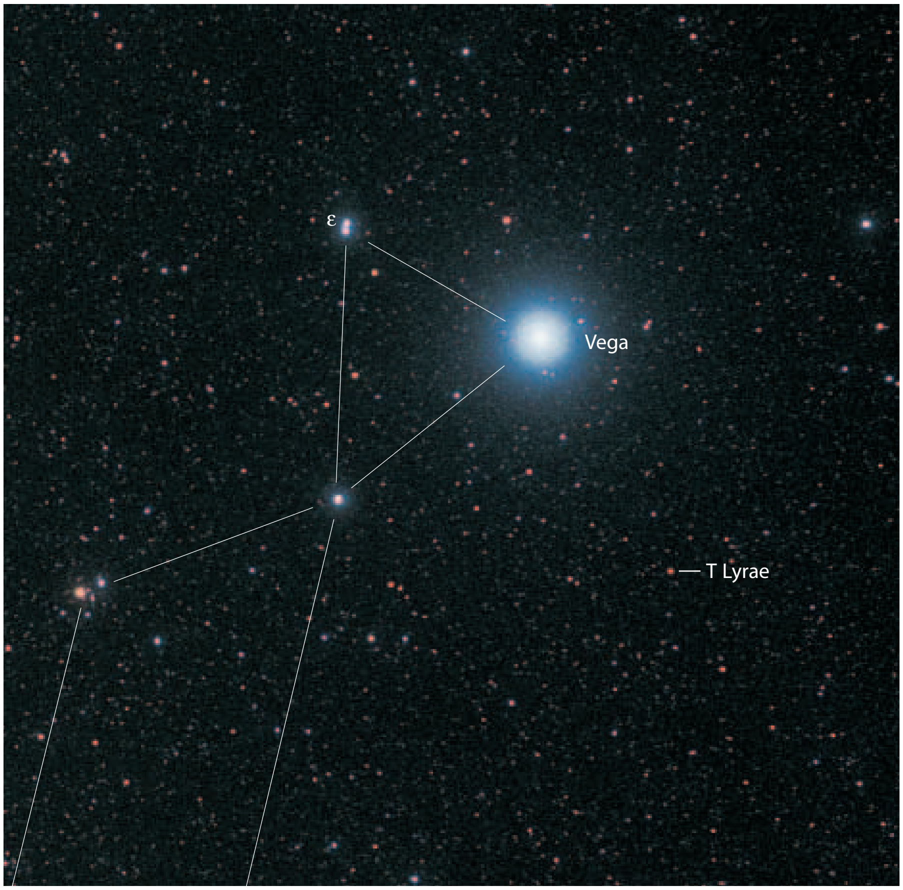
Thanks to my red-deficient color vision (common among men but rare among women), the 9th-magnitude star looked completely colorless to me. But I knew from my measurements through blue and yellow filters that it must indeed be deeply colored.

I had always been amazed that even novice observers looking at Orion see a distinct color contrast between Betelgeuse and Rigel — orange-red and pale blue-white, respectively. To me they look practically alike. Since stop signs and apples do look "red" to me, I began to wonder if any stars are red enough for me to see strong color in them. After poking around in the observatory library, and with a few hints from fellow amateurs, I found the answer: carbon stars.

Astronomers often describe a star's color by its *color index*. This is simply the difference in the star's magnitude as measured through two different standard color filters.

The most commonly used color index is the difference between a star's brightness measured through a broadband blue (B) and a "visual" (V) filter. The V filter passes the yellow and green wavelengths to which our eyes are the most sensitive; the filter itself looks pale straw color. This is why color index is often written as B–V ("B minus V"). Its value turns out to be closely related to a star's surface temperature.

On this scale, a star that most people



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Above: **Easily spied 2° south-southwest of Vega, the carbon star T Lyrae has an extreme B–V color index of about 5.5, making it one of the reddest stars in the sky. It has varied irregularly between magnitudes 7.8 and 9.6; it's sometimes visible in binoculars and always colorful in a telescope.** ***Left:*** **Author Brian Skiff has red-deficient color vision; even red supergiant stars such as Betelgeuse and Antares look nearly white to him. But even he perceives carbon stars as red. Here Skiff stands with the 21-inch telescope at Lowell Observatory in Flagstaff, Arizona, which he uses to measure star brightnesses and colors photoelectrically.**

would call "pure white" has a color index of +0.2 or +0.3. Vega and Sirius, white with just a hint of blue, are 0.0. The hottest, bluest stars, such as Spica, Bellatrix, and the stars of Orion's Belt, have a negative B–V of about –0.25.

The pale yellow Sun has a B–V color of about +0.65. (In a large telescope I see such stars as exactly white.) Cooler Arcturus and Aldebaran have B–Vs of about +1.0 and +1.5, respectively; most people see them as pale yellowish orange to pale orange-red. (See "The Truth About Star Colors," *S&T:* September 1992, page 266.)

The reddest ordinary stars are *M*-type supergiants such as Betelgeuse and Antares, both of whose B–Vs are about +1.85. But to me, even through a telescope, these stars appear more yellow than red.

Carbon Stars

Strongly colored stars have always fascinated astronomers. The long history of red-star observations begins in the early 19th century. Such famous observers as Angelo Secchi, Nils C. Dunér, and Thomas E. Espin found red stars of interest not only for their strong color but also because they provided a rich lode for hunting new variables. The pioneering visual spectroscopists (starting with Secchi around 1860) also found their complex spectra to be of extreme curiosity. In 1890 Espin produced a catalog of 766 red stars, including detailed observations of their colors and variability as well as descriptions of their spectra.

In his visual surveys with an eyepiece spectroscope, Secchi found that most stars fit into three broad categories. Bluish white stars such as Sirius showed a spectrum marked only by a few strong dark lines, now known to be due to hydrogen absorption. Another group, including the Sun, showed additional, weaker lines. In a third class were redder stars such as Antares and Betelgeuse, which had innumerable fine lines as well as several broad, dark bands. It was not until early this century that these dark bands were found to result from titanium oxide (TiO) molecules.

Before long Secchi also isolated a fourth class, which were generally among the reddest of stars. These also showed dark spectral bands, but the pattern was different from those in the Antares-like stars. Secchi himself identified these bands as being due to carbon, which he deduced by comparing the stellar spectra to the flame spectrum of paraffin in a laboratory. These very red stars are now called "carbon stars." The image of a star surrounded by soot and smoke also turns out to be appropriate.

How does so much carbon end up in a star's atmosphere? After a star of about the Sun's mass enters the red-giant phase of its evolution, convective currents circulate deep into the stellar interior. Heavy elements such as carbon, which were created by nuclear fusion earlier in the star's life, are brought up to the surface. The bands in the visible part of the spectrum are the fingerprints of molecules (such as C_3, CN, and CH) formed by the dredged-up carbon. The TiO bands are absent.

Ordinary orange-red stars like Betelgeuse get their color from their low surface temperatures. Carbon stars are also cool giants, but they are deeper red because the blue and violet portions of their spectra are almost completely absorbed by the various molecules in their atmospheres. In other words, they are wrapped in gaseous red filters.

Stellar astronomers think of carbon stars as forming a sequence parallel to the ordinary cool giants. Although they are classified in a distinct bin (spectral type *C*), carbon stars actually form a continuum — from those showing mere traces of carbon (and much oxygen) to those where carbon dominates the spectrum. Carbon-star spectra includes two numbers, such as *C*5,4. The first indicates decreasing temperature from 0 to 9, while the second indicates the strength of the carbon-related molecules on a scale of 1 to 5. A type *C*5,4 star has a temperature similar to a normal red giant near type *M*0, and it has strong C_2 bands. (As in other spectral types, *e* indicates the presence of emission lines.)

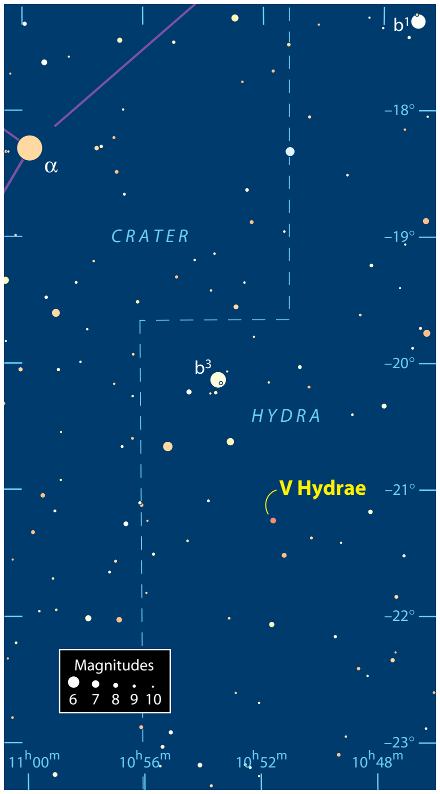
Carbon stars are rare. A mere handful are easily visible to the naked eye, and only about 200 appear among the half million stars brighter than magnitude 9. But they have been searched out more assiduously than any other spectral class of star. The most recent catalog of them, published in 1989 by C. Bruce Stephenson, includes 6,000 entries, nearly all fainter than visual magnitude 12.

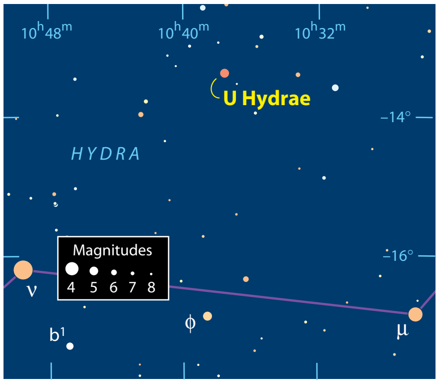
The table below shows some representative carbon stars and a few well-known "ordinary" red stars for comparison. The table includes *approximate* V (visual) magnitudes and B–V colors. All but one of these stars are variable (and that one star is merely unstudied for variability). Some display large changes in brightness (the carbon Miras), so the magnitudes refer to either a typical brightness or a magnitude near maximum.

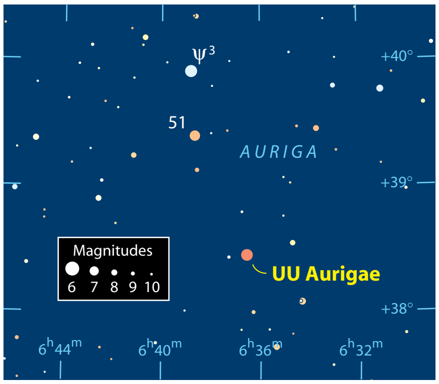
Some Very Red Stars

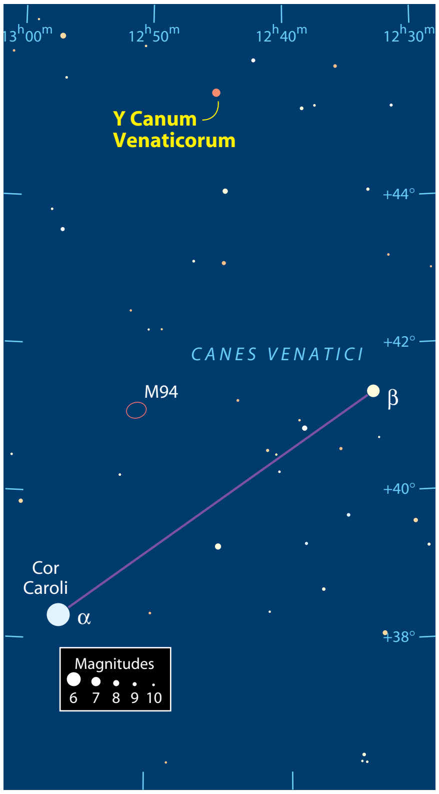
Name	R. A. (2000)	Dec.	Typical V Mag.	B–V	Range of V Mag.	Spectral Type	Period (Days)	Type of Variable
VX And	$0^h\ 19^m\ 54^s$	+44° 42.6'	8.5	4.4	7.8–9.3	*C*5,4	369	Carbon Mira
V466 Cas	$1^h\ 19^m\ 54^s$	+58° 18.5'	8.5	2.1	8.0–9.0	*M*0.5Ib	—	Irregular
R Scl	$1^h\ 26^m\ 58^s$	–32° 32.6'	6	4.0	5.0–9.0	*C*6,5	370	Carbon Mira
RS Per	$2^h\ 22^m\ 24^s$	+57° 06.6'	8.5	2.3	7.8–10.0	*M*3+Iab	152?	Irregular?
R Dor	$4^h\ 36^m\ 46^s$	–62° 04.6'	5.5	1.6	4.8–6.6	*M*8IIIe	338?	Carbon Mira
R Lep	$4^h\ 59^m\ 36^s$	–14° 48.4'	7	5.5	5.5–11.7	*C*7,4e	427	Carbon Mira
UU Aur	$6^h\ 36^m\ 33^s$	+38° 26.7'	6	2.6	5.3–6.5	*C*5,3	235?	Semiregular
U Hya	$10^h\ 37^m\ 33^s$	–13° 23.1'	5	2.6	4.8–6.5	*C*7,3	450	Semiregular
V Hya	$10^h\ 51^m\ 37^s$	–21° 15.0'	7	5.5	6.0–12.0	*C*7,5e	550	Semiregular
SS Vir	$12^h\ 25^m\ 20^s$	+0° 47.8'	8	4.2	6.0–9.6	*C*6,3e	355	Carbon Mira
Y CVn	$12^h\ 45^m\ 08^s$	+45° 26.4'	5	2.5	4.8–6.5	*C*5,4	158	Semiregular
E-B 365	$12^h\ 47^m\ 25^s$	–59° 41.7'	9	5.8		*C*		
V CrB	$15^h\ 49^m\ 31^s$	+39° 34.3'	8	4.4	6.9–12.2	*C*6,3	358	Carbon Mira
V Pav	$17^h\ 43^m\ 19^s$	–57° 43.4'	7	4.0	7.5–13.8	*C*5,4	229	Semiregular
T Lyr	$18^h\ 32^m\ 20^s$	+36° 59.9'	8.5	5.5	7.8–9.6	*C*6,5	—	Irregular
V Aql	$19^h\ 04^m\ 24^s$	–5° 41.1'	7	4.2	6.6–8.4	*C*5,4	353	Carbon Mira
UX Dra	$19^h\ 21^m\ 36^s$	+76° 33.6'	6	2.9	5.9–7.1	*C*6,4	168	Semiregular
RS Cyg	$20^h\ 13^m\ 24^s$	+38° 43.7'	7.5	3.0	6.5–9.7	*C*8,2e	417	Carbon Mira
Mu Cep	$21^h\ 43^m\ 30^s$	+58° 46.8'	4	2.5	3.4–5.1	*M*2Ia	730?	Irregular
LW Cyg	$21^h\ 55^m\ 14^s$	+50° 29.8'	9	4.2	8.5–10?	*C*4,2	—	Irregular
19 Psc	$23^h\ 46^m\ 24^s$	+3° 29.2'	5	2.5	4.5–5.3	*C*7,2	220	Semiregular

The B–V colors in the table cannot be considered precise. In addition to some innate variability in the color index, the standard photometric systems are not defined for stars redder than ordinary *M*









giants, so large systematic deviations occur when different filters and photomultiplier tubes (or CCDs) are used for the measurements.

Nevertheless, the large B–V values give some indication of what to expect at the eyepiece. While "red" stars are usually thought of as having colors of 1.5 to 2.0, several stars here have had their B–V measured as high as 5.5!

Some are bright enough for their strong color to be evident in binoculars. Others require a telescope. Remember that the part of your eye most sensitive to color is the fovea, the center of your vision. So you want to look right at these stars, unlike in much deep-sky observing, where the emphasis is on averted vision.

A Spring Collection

Compare **V Hydrae** to HD 94073, the 8th-magnitude star ¼° to its south-southwest. According to the new Hipparcos catalog, HD 94073 has a B–V of 1.66, slightly redder than Aldebaran. Yet its paleness next to deep-red V Hydrae is striking.

V Hydrae normally ranges between magnitude 7 and 9 in about 17 months. But about every 18 years dust condenses around the star, causing it to dim to as faint as magnitude 12. The most recent dimming occurred in the mid-1990s; since then V Hydrae has slowly recovered to nearly its usual brightness.

A bipolar (two-sided) outflow of material from the star has been observed at infrared and radio wavelengths, suggestive of the structures seen in planetary nebulae. Perhaps this is a sign that V Hydrae is already making its expected transition from the red-giant stage to a planetary nebula.

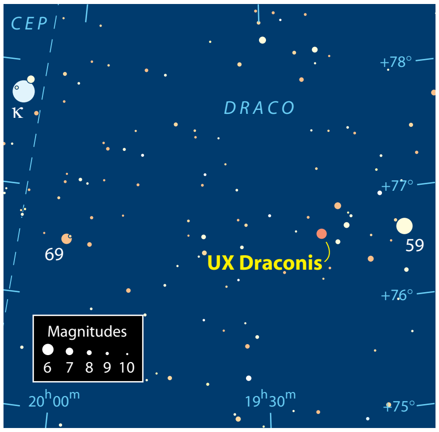
About 9° north-northwest of V Hydrae is the brighter but less-red carbon star **U Hydrae**. It's bright enough that its red color should be distinctive in binoculars. U Hydrae normally remains about 5th magnitude. Its brightness suggests that it is among the nearest carbon stars. Indeed, the Hipparcos spacecraft supplies us with a parallax measurement that puts it 520 light-years away with an uncertainty of only 10 percent.

Three other bright but not extremely red carbon stars lie in the northern spring sky. In the eastern reaches of Auriga, about 7° east-northeast of Theta (θ) Aurigae, is 6th-magnitude **UU Aurigae.** One of the first carbon stars found, it was noted as very red by the French astronomer J.-J. Lalande in the late 18th century. It hovers between magnitude 5.5 and 6.0.

Nearly overhead these evenings, only 4° northeast of Beta (β) Canum Venaticorum, is **Y Canum Venaticorum.** Secchi named it "La Superba." It generally remains between magnitude 5 and 6. The Hipparcos parallax puts the star some 720 light-years away, almost directly above the plane of the galaxy.

Finally, in the northeast is **UX Draconis,** a circumpolar object for most Northern Hemisphere observers. It lies only 2¾° southwest of Kappa (κ) Cephei. It's a little fainter than Y Canum (between 6th and 7th magnitude) but is still a striking sight in a telescope.

The easiest carbon star to find in the whole sky — if you live in the Southern Hemisphere — is also one of the reddest. Just 2' west of 1st-magnitude Beta (β) Crucis, the eastern star of the Southern Cross, is **Espin-Birmingham 365.** Although it was observed as early as the 1830s by John Herschel, it has no modern designa-



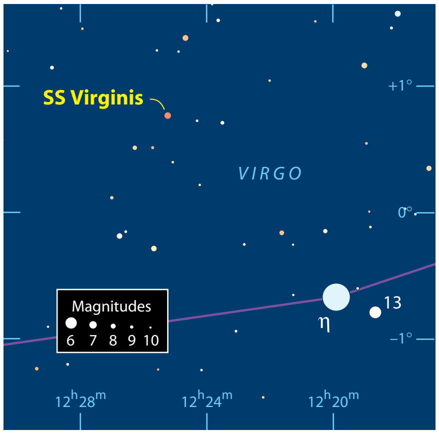
tion other than its entry in Stephenson's carbon-star catalog. It was rediscovered as a carbon star after World War II by A. D. Thackeray in South Africa, but no published observations show it to be variable.

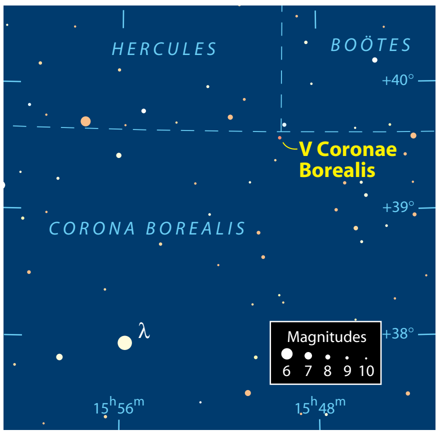
Several times astrophotographers have asked me about this conspicuous, 9th-magnitude red dot on their color photos of the Southern Cross. As the table shows, it is one of the reddest stars known, at B–V = 5.8, so that in color filmi the red emulsion layer is the only one exposed. It looks like a photo defect!

Two quite red variable stars — **SS Virginis** and **V Coronae Borealis** — are known as "carbon Miras" because of their long periods. Ordinary Miras are *M* giants with B–V colors between about 1.5 and 2.0, in contrast to about 4.3 for these two carbon stars.

SS Virginis lies about 2° northeast of Eta (η) Virginis near the ecliptic, where it can be occulted by the Moon. Last summer Mars passed near the star, causing some observers to comment on its extraordinary color compared to the much paler "red planet."

V Coronae Borealis is 2° northwest of Lambda (λ) Coronae Borealis. Like other Miras both stars have a large brightness

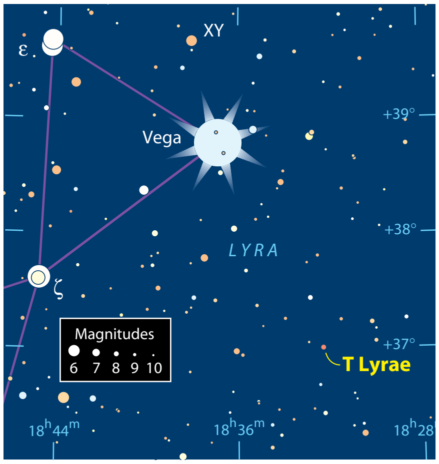


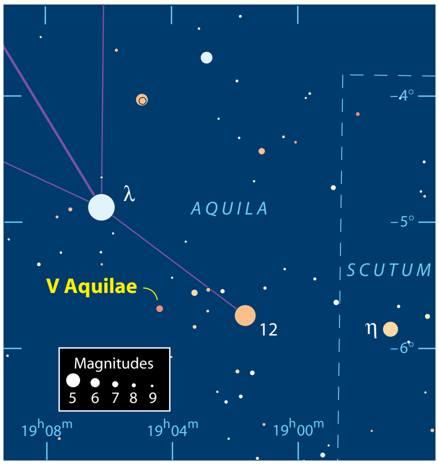


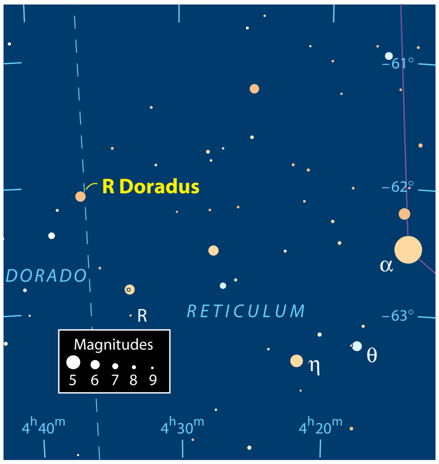
range (getting as faint as magnitude 12), so sometimes they are not readily visible.

Summer and Autumn Stars

As summer approaches be sure to scout out **T Lyrae** about 2° southwest of Vega. Its extreme B–V color (5.5) makes it a sure winner even for those of us who are colorblind. Compare T Lyrae to orange HD 170970, the star of similar brightness (about magnitude 7.5) less than 1° to its southwest. This is a garden-variety red giant with a spectral type of *M*3 and a







B–V of 1.57 from the Hipparcos catalog. (It was found to be slightly variable by Hipparcos, and its newly assigned variable-star name, V530 Lyrae, appears in the *Millennium Star Atlas.*)

The "carbon Mira" **V Aquilae** is in the circlet of stars marking Aquila's tail, near Messier 11. Compare this to any ordinary Mira of similar brightness, and you'll see how distinctive the carbon stars are. T Lyrae and V Aquilae are nice show objects for public star parties.

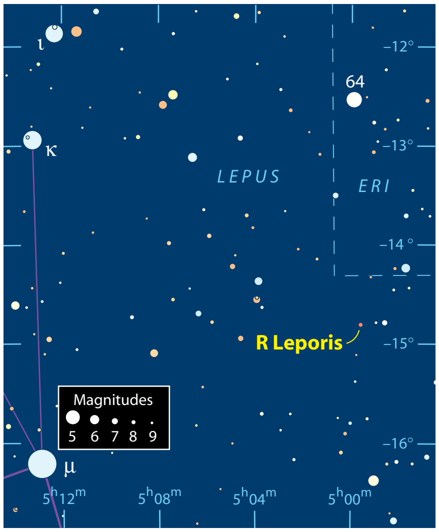
It's common to see a single distinctively red star in an open cluster. None of these, however, is a carbon star. Instead they are *K* or *M* giants or supergiants, two examples of which are given in the table. **V466 Cassiopeiae** resides in the bright cluster NGC 457, on the north side of the main clump. Since it is relatively faint an 8-inch or larger telescope will be necessary to distinguish it from the bluer cluster members.

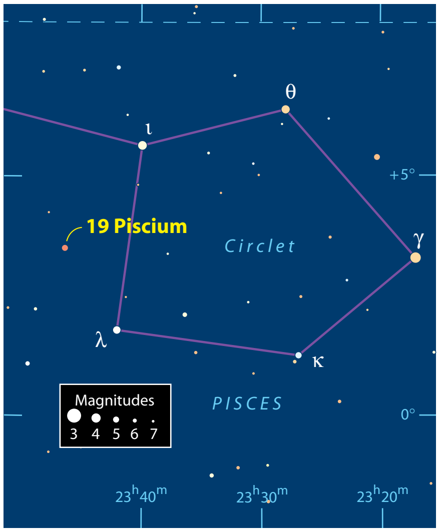
RS Persei is easier to pick out. It is one of about 20 *M*-supergiant variables centered on the eastern cluster (NGC 884) of the Perseus Double Cluster. RS Persei is on the southeastern side of the cluster core; it's the reddest star near the center. RS Persei has been reported as faint as magnitude 10 only once; it usually spends its time around magnitude 8.5. (For more on red stars in the Double Cluster, including a map, see the December 1994 issue, page 46.)

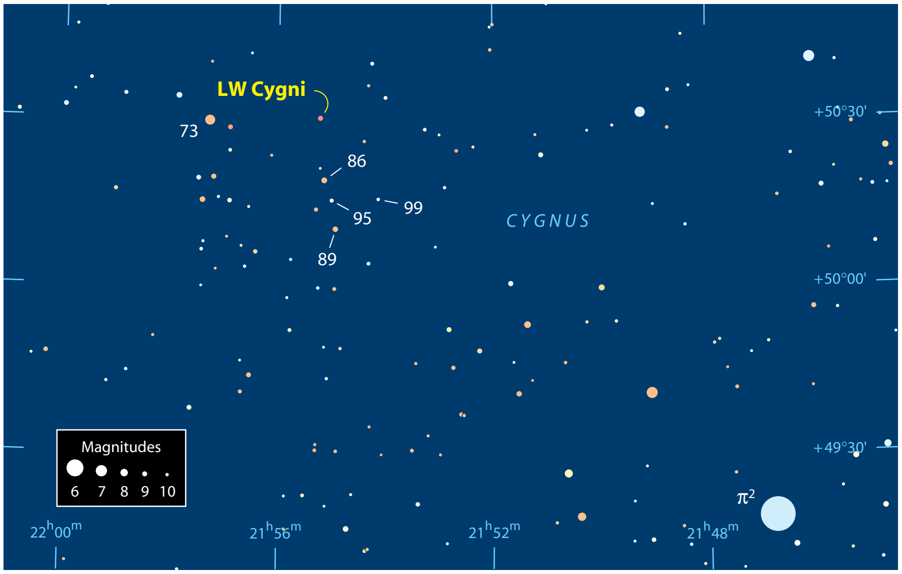
Two other *M*-type variables in the table have comparatively "blue" colors. **R Doradus,** 2½° east-northeast of Alpha (α) Reticuli in the far southern sky, is the brightest star to have a spectral type as late as *M*8. It is among the nearest *M* giants, 200 light-years away according to the very reliable Hipparcos parallax measurement. If we could stick a thermometer into its surface we'd probably find this star to have the lowest temperature of any on the list. But the B–V color is the least red!

Just as far into the northern sky is somewhat brighter **Mu (μ) Cephei,** long known as "Herschel's Garnet Star." It ranks as the reddest star easily visible to the unaided eye, though I need at least binoculars to see its tint.

Another bright variable, **R Leporis,** is known as "Hind's Crimson Star" after another active 19th-century observer. In this case the B–V color (5.5) indicates the name is justified. This roughly 7th-magnitude ember can be found about 3½° northwest of Mu Leporis. More about it is in the March 1994 issue, page 73.







The brightest carbon star in the sky is **19 Piscium (TX Piscium)** in the eastern edge of the Circlet asterism under the Square of Pegasus. Its color is not extreme but conspicuous even so. The fourth *General Catalogue of Variable Stars* classes it among the irregular variables. But Maryland amateur Rick Wasatonic recently monitored it for several years from his backyard using an 8-inch Schmidt-Cassegrain telescope and a solid-state photometer. He found the variations to be well defined, showing an average cycle length near 220 days with a brightness range of magnitude 4.5 to 5.3.

The chart for the red variable **LW Cygni** above gives some V magnitudes that I measured for comparison stars in the field. (The decimal points are omitted.) This star was first noticed by the amateur observers John Birmingham and Thomas W. Webb in the 1870s. Later Dunér and Espin, using visual spectroscopes, were the first to see its carbon signature.

LW Cygni may undergo episodes of strong dimming, perhaps caused by carbon soot condensing in its outer atmosphere. But I could not find any actual observations of this in the literature. Despite catalog claims of it getting as faint as magnitude 14, all published data show it between magnitude 8 and 10. This is not a commonly observed star in any case, so it makes a good target for amateurs. It's accessible to Northern Hemisphere observers practically all year, lying in a gorgeous field near the Cygnus-Cepheus border.

One of the world's most respected deep-sky observers, Brian A. Skiff *is a research assistant at Lowell Observatory and coauthor of the* Observing Handbook and Catalogue of Deep-Sky Objects *with Christian Luginbuhl.*