SPECIAL STARS ISSUE

Making sense of stars

Two early-20th-century astronomers first saw patterns in the rich diversity of stars. /// BY RICHARD TALCOTT; ILLUSTRATION BY LYNETTE COOK

Scan the night sky, and you'll see stars of every hue. The dazzling blue of Rigel contrasts with the ruddy glow of Betelgeuse, and neither would be confused with the pure white of Sirius or the yellow gleam of Capella. Even faint stars, when magnified by a telescope, show a range of colors. What does it all mean?

The answer came through the efforts of Danish astronomer Ejnar Hertzsprung (1873–1967) and American astronomer Henry Norris Russell (1877–1957). In the early 20th century, they independently plotted the intrinsic brightness of stars against temperature (which determines color). Today, astronomers understand stellar diversity with the Hertzsprung–Russell (H–R) diagram, named in the scientists' honor. A modern version appears at right.

The H–R diagram's vertical axis plots a star's brightness, measured in luminosity, or absolute magnitude (the star's apparent magnitude if it were 32.6 light-years away). Bright stars lie near the top; faint stars near the bottom. The horizontal axis plots a star's temperature, or spectral type. Hot, blue stars lie to the left; cool, red stars to the right.

The diagram shows that about 95 percent of stars lie along a narrow strip that runs from upper left to lower right. This so-called main sequence represents stars burning hydrogen into helium. Fewer than 1 percent of stars belong to the giant and supergiant classes at top, even though many of these rank among the sky's brightest. At bottom, the dying cinders known as white dwarfs make up about 5 percent of stars.

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"IT SEEMS CLEAR THAT . . . there is a real lack of red stars comparable in brightness to the Sun." — *Henry Norris Russell*

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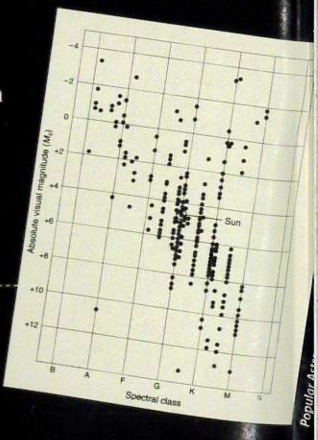
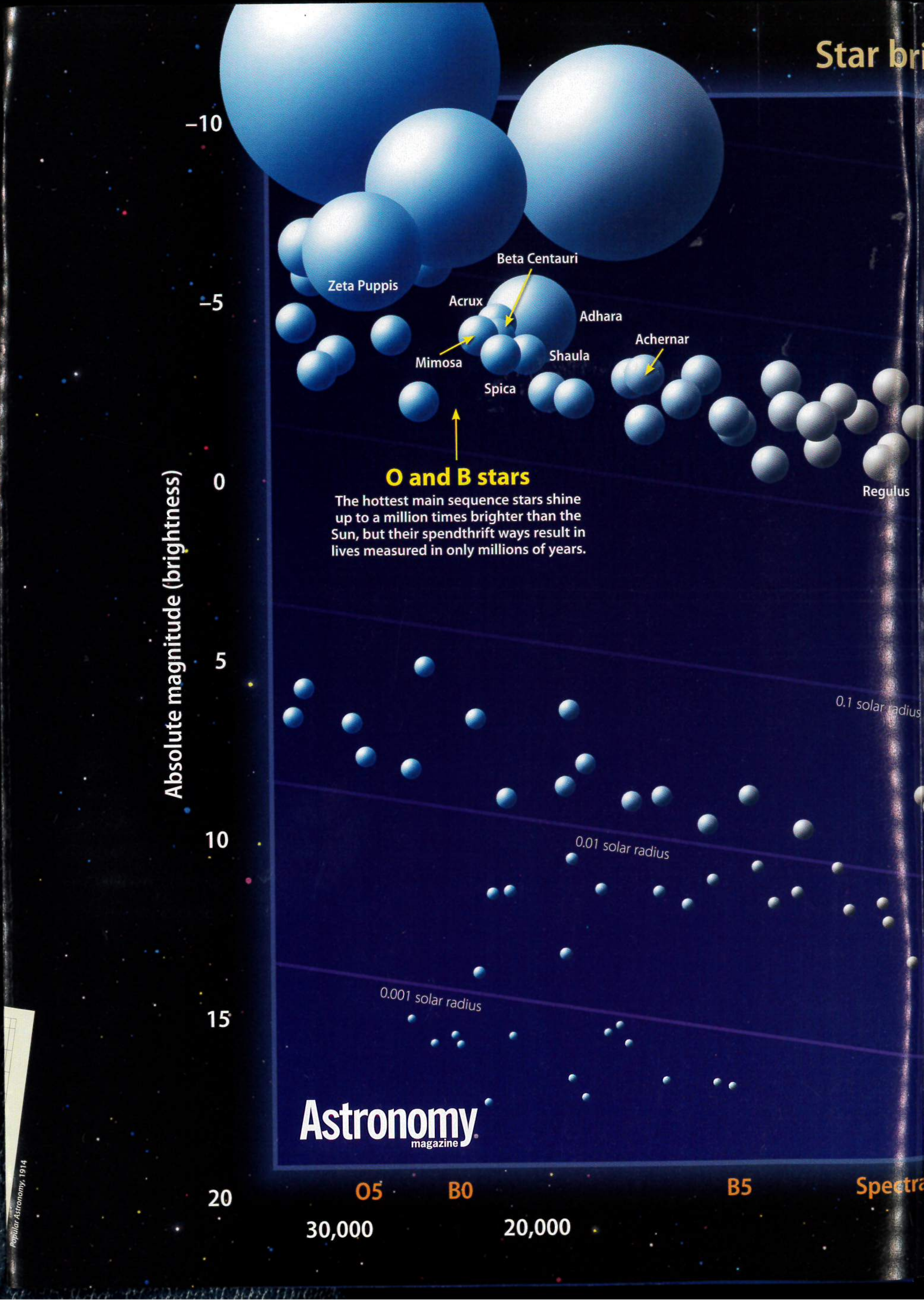
"WHY NOT CALL IT the color-magnitude diagram? Then we know what it is all about." — *Ejnar Hertzsprung*



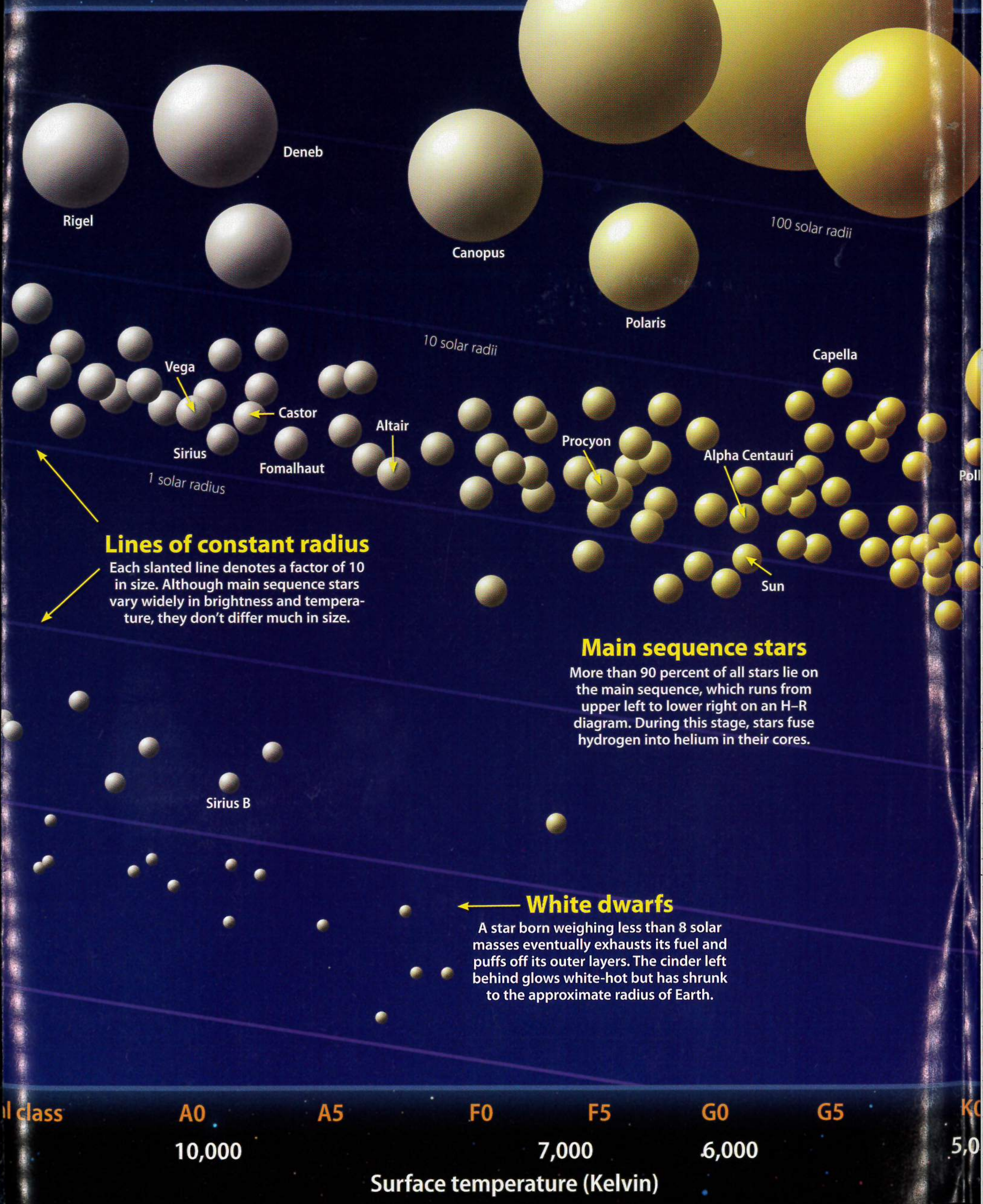
RUSSELL'S ORIGINAL DIAGRAM clearly shows most stars lie on a strip running from upper left to lower right.

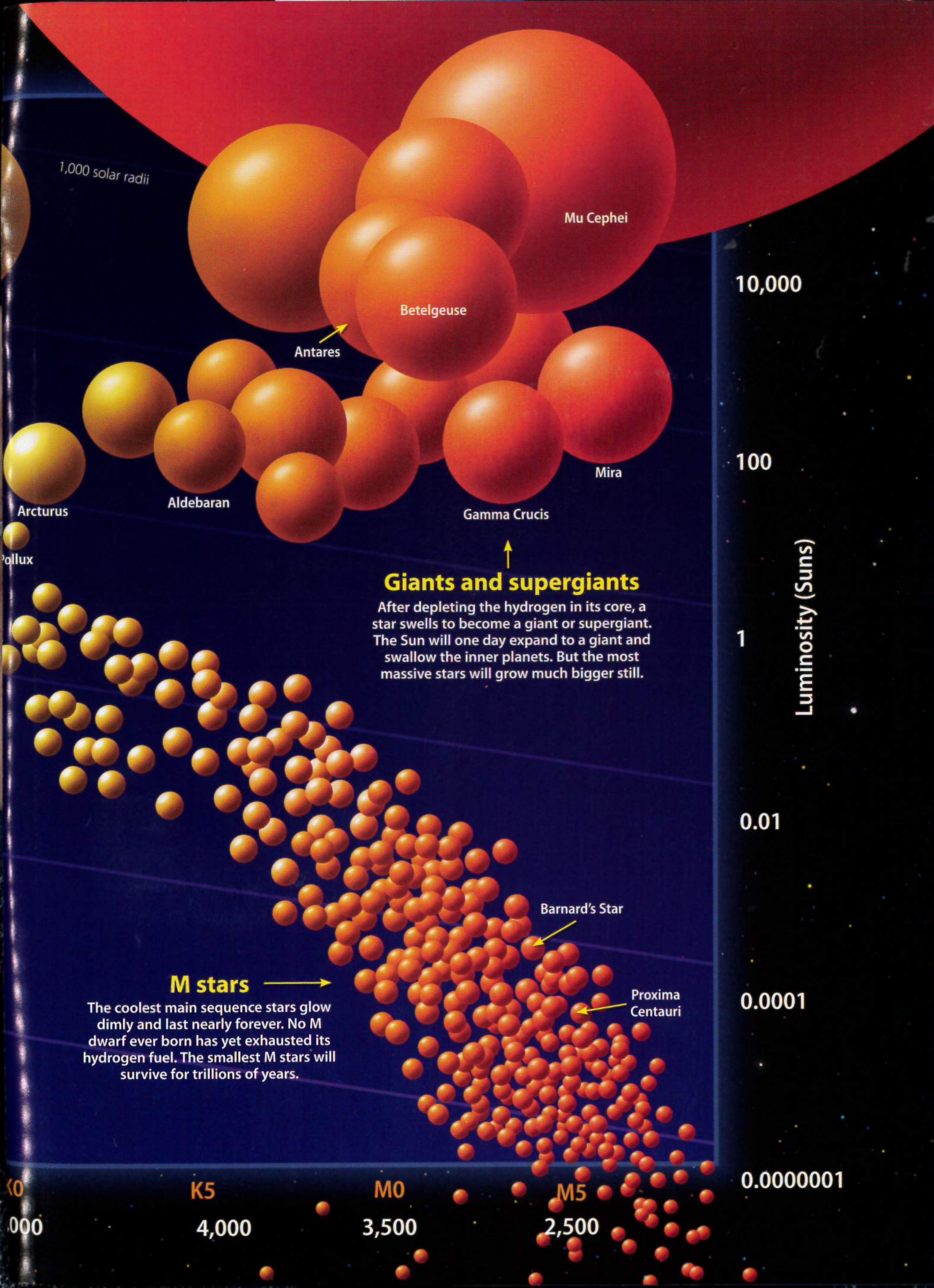
Richard Talcott *is the senior editor of* Astronomy. **Lynette Cook** *is an illustrator living in Daly City, California.*



Absolute magnitude (brightness)
–10
–5
0
5
10
15
20
Zeta Puppis
Beta Centauri
Acrux
Adhara
Mimosa
Shaula
Achernar
Spica
Regulus
O and B stars
The hottest main sequence stars shine up to a million times brighter than the Sun, but their spendthrift ways result in lives measured in only millions of years.
0.1 solar radius
0.01 solar radius
0.001 solar radius
Astronomy magazine
O5
B0
B5
30,000
20,000

ightness vs. temperature



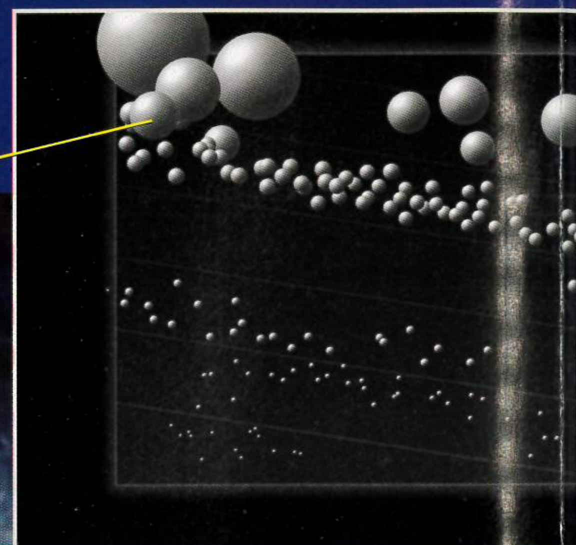

1,000 solar radii
Mu Cephei
10,000
Betelgeuse
Antares
100
Mira
Arcturus
Aldebaran
Gamma Crucis
Pollux
Giants and supergiants
After depleting the hydrogen in its core, a star swells to become a giant or supergiant. The Sun will one day expand to a giant and swallow the inner planets. But the most massive stars will grow much bigger still.
1
Luminosity (Suns)
0.01
Barnard's Star
M stars
The coolest main sequence stars glow dimly and last nearly forever. No M dwarf ever born has yet exhausted its hydrogen fuel. The smallest M stars will survive for trillions of years.
Proxima Centauri
0.0001
0.0000001
K0
K5
M0
M5
4,000
3,500
2,500

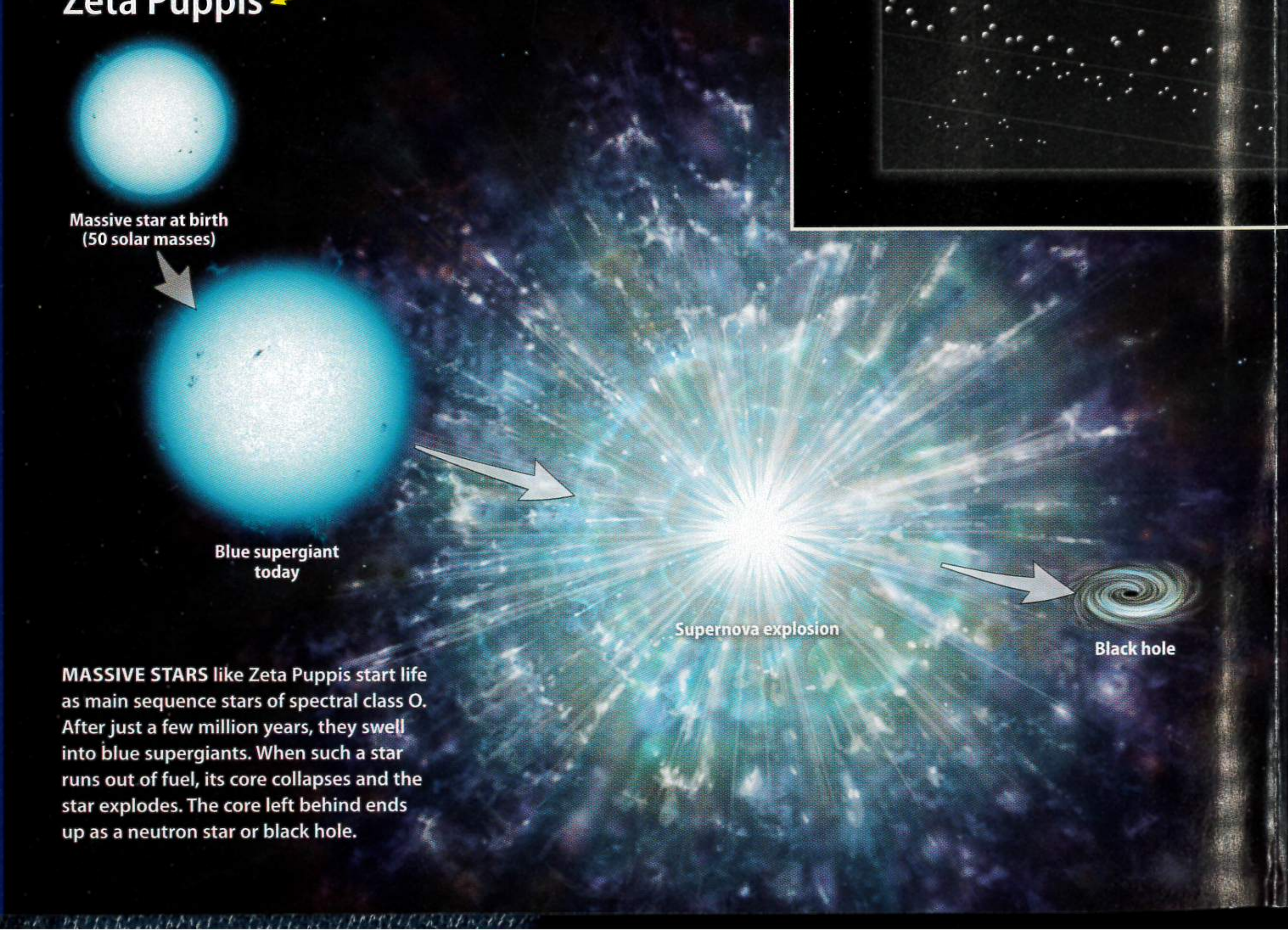
NASA/JPL-CALTECH/L. ALLEN (HARVARD-SMITHSONIAN CfA)

NASA AND THE HUBBLE HERITAGE TEAM (STScI/AURA)

THE STAR CLUSTER HODGE 301 (at lower right) formed within the past several million years out of gas and dust in the Tarantula Nebula, located in the Milky Way's satellite galaxy, the Large Magellanic Cloud. Despite its relative youth, the cluster has already seen some massive stars complete their lives and explode as supernovae. Shock waves from the explosions have compressed some of the Tarantula's gas into sheets and filaments.

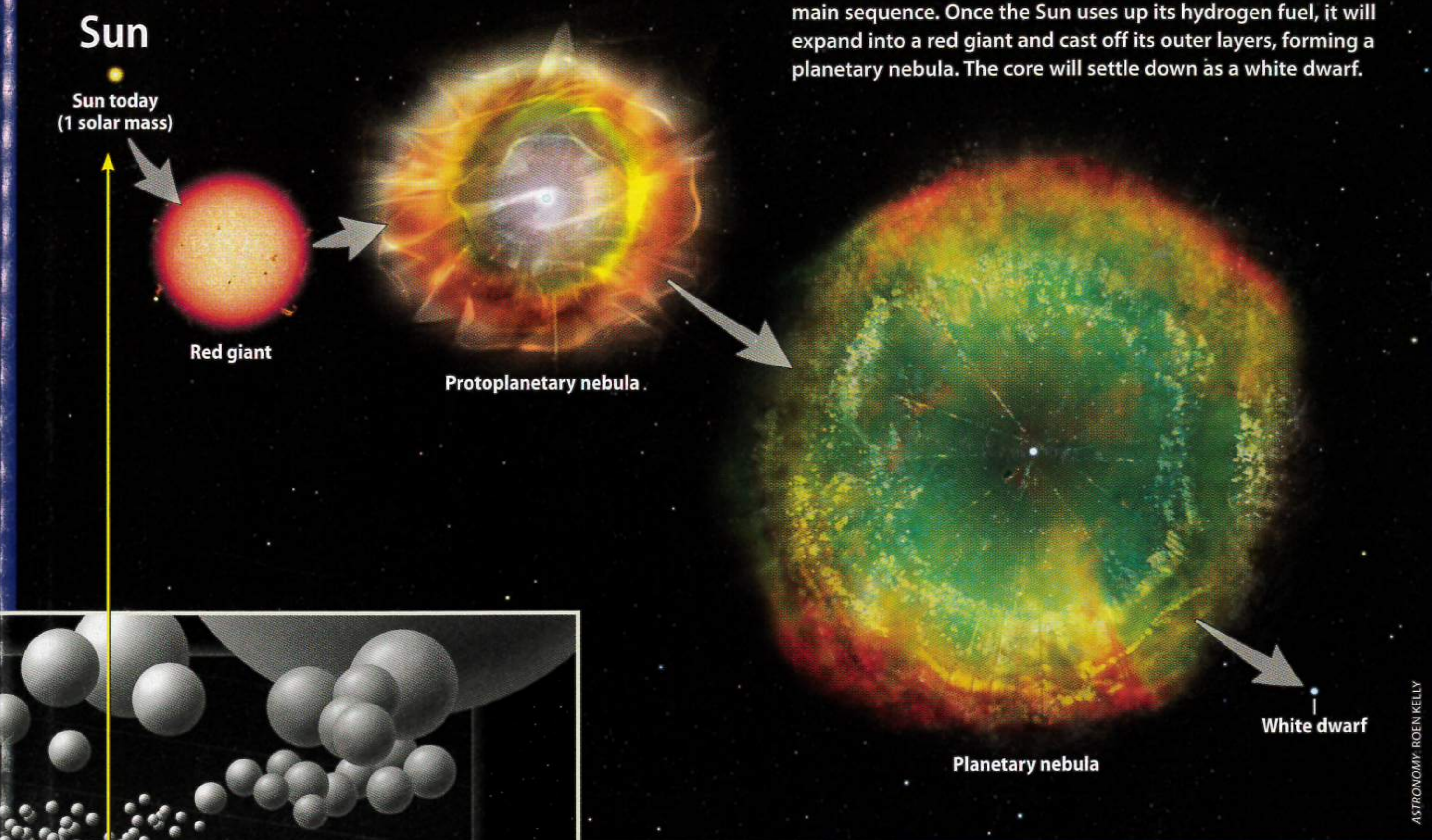
STARS FORM INSIDE INTERSTELLAR CLOUDS of gas and dust when an outside force triggers the cloud to gravitationally contract. This natal cocoon, which goes by the prosaic designation W5, lies 7,000 light-years from Earth in Cassiopeia. The infrared radiation captured in this image penetrates the cloud's dust, revealing newborn stars with masses similar to the Sun.

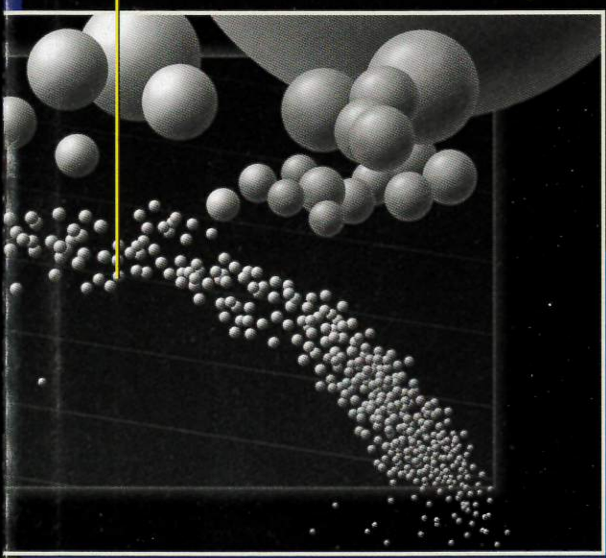




MASSIVE STARS like Zeta Puppis start life as main sequence stars of spectral class O. After just a few million years, they swell into blue supergiants. When such a star runs out of fuel, its core collapses and the star explodes. The core left behind ends up as a neutron star or black hole.

STARS LIKE THE SUN spend roughly 10 billion years on the main sequence. Once the Sun uses up its hydrogen fuel, it will expand into a red giant and cast off its outer layers, forming a planetary nebula. The core will settle down as a white dwarf.



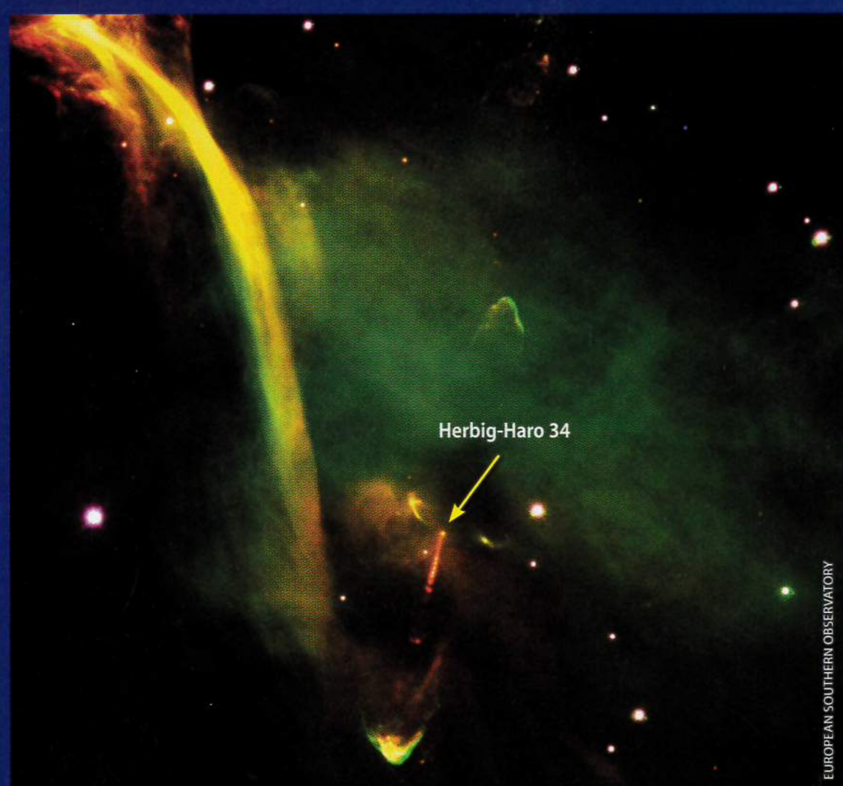


ASTRONOMY: ROEN KELLY

NASA AND THE HUBBLE HERITAGE TEAM (STScI/AURA)

STARS USUALLY FORM IN CLUSTERS. Some become globular clusters like M80, which contains hundreds of thousands of stars held together by their mutual gravitational attraction. All of the Milky Way's globular clusters formed at the same time the galaxy did, and orbit within the galaxy's halo. Globulars contain so many stars, their gravity has held them together since the galaxy's birth 13 billion years ago.

ASTRONOMY: ROEN KELLY



EUROPEAN SOUTHERN OBSERVATORY

THE FINAL FITS AND STARTS before a star fully forms show up in the protostar Herbig-Haro 34, located 1,500 light-years away near the Orion Nebula. The protostar has ejected two opposite jets of dense gas into the surrounding interstellar medium at speeds of 150 miles per second. The jets imply repeated outbursts arise when large chunks of material from a surrounding disk falls onto the protostar.

Astronomy magazine

The secret lives of stars

Stars are born in gaseous clouds, live long, unassuming lives, and die in sometimes dramatic ways. /// BY RICHARD TALCOTT

/// THE 25 BRIGHTEST STARS

Name	R. A.	Dec.	Mag.	Abs. mag.	Spectral type	Luminosity class	Distance
Sirius*	6h45.1m	−16°43'	−1.47	1.4	A1	V	8.58
Canopus	6h24.0m	−52°42'	−0.72	−5.6	F0	II	313
Alpha Centauri*	14h39.6m	−60°50'	−0.29	4.1	G2	V	4.36
Arcturus	14h15.7m	19°11'	−0.04	−0.3	K1.5	III	36.7
Vega*	18h36.9m	38°47'	0.03	0.6	A0	V	25.3
Capella*	5h16.7m	46°00'	0.08	−0.5	G5	III	42.2
Rigel*	5h14.5m	−8°12'	0.12	−6.8	B8	Iab	773
Procyon*	7h39.3m	5°13'	0.34	2.6	F5	IV–V	11.4
Achernar	1h37.7m	−57°14'	0.50	−2.7	B3	V	144
Betelgeuse*	5h55.2m	7°24'	0.58	−5.0	M2	Iab	522
Beta Centauri*	14h03.8m	−60°22'	0.60	−5.4	B1	III	525
Altair*	19h50.8m	8°52'	0.77	2.2	A7	V	16.8
Aldebaran*	4h35.9m	16°31'	0.85	−0.7	K5	III	65.1
Acrux*	12h26.6m	−63°06'	0.94	−4.0	B1	IV	321
Spica*	13h25.2m	−11°10'	1.04	−3.5	B1	III–IV	262
Antares*	16h29.4m	−26°26'	1.09	−5.2	M1.5	Ib	604
Pollux*	7h45.3m	28°02'	1.15	0.8	K0	III	37.6
Fomalhaut	22h57.7m	−29°37'	1.16	1.7	A3	V	25.1
Deneb*	20h41.4m	45°17'	1.25	−7.5	A2	Ia	1,500
Mimosa*	12h47.7m	−59°41'	1.30	−3.9	B0.5	IV	352
Regulus*	10h08.4m	11°58'	1.35	−0.5	B7	V	77.5
Adhara*	6h58.6m	−28°58'	1.51	−4.1	B2	Iab	431
Castor*	7h34.6m	31°53'	1.59	0.6	A2	V	51.5
Shaula*	17h33.6m	−37°06'	1.62	−3.6	B2	IV	359
Gamma Crucis*	12h31.2m	−57°07'	1.63	−0.5	M3.5	III	87.9

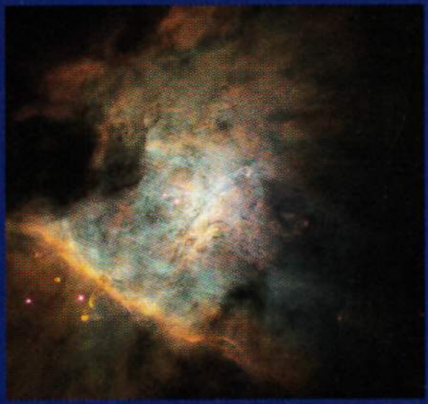
* Stars with more than one component. Magnitudes combine all components; spectral types just the brightest member. (The H–R diagram on the other side plots only the brightest component.)

R. A. and Dec.: Right ascension and declination in epoch 2000.0 coordinates. **Mag.:** Apparent visual magnitude. **Abs. mag.:** Absolute visual magnitude (apparent magnitude if star lay 32.6 light-years away). **Spectral type and luminosity class:** Based on the Morgan–Keenan system. **Distance:** Measured in light-years.

If you want to learn about stars, take a census of the heavens. You'll soon find a major complication, however — the results depend on how you define the search. Examine the brightest stars, and you'll discover lots of giant and supergiant ones, with only a smattering of main sequence stars like the Sun. Study the nearest stars, and you'll find almost all belong to the main sequence — and most are far cooler and dimmer than the Sun.

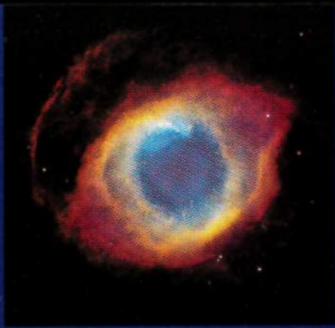
The brightest stars stand out because they pour huge amounts of energy into space. The supergiant Deneb radiates nearly 100,000 times as much light as the Sun and more than a billion times as much as nearby Proxima Centauri. But the bright, hot stars pay for their profligacy. They run through their nuclear fuel reserves far faster than their fainter, cooler cousins. The O5 star Zeta Puppis will survive only a few million years; M5.5 star Proxima Centauri will be around long after the Sun ceases to exist, and will look much as it does today when the universe is 100 times its current age.

Astronomy's poster summarizes the nearest and brightest stars, as well as the big and small and the hot and cool. It's your complete guide to the births, lives, and deaths of the Milky Way's basic building blocks. ◼



C. R. O'DELL AND S. K. WONG (RICE UNIVERSITY) AND NASA

STARS BEGIN TO EMERGE from the Orion Nebula, a massive star-forming region known to observers around the world. In this visible-light image, the four brightest stars — called the Trapezium — show up just left of center. These hot O-type stars radiate much of the energy needed to energize the nebula. They are the vanguard in what eventually will be a huge star cluster.



NASA, ESA, C. R. O'DELL (VANDERBILT)

WHEN A SUN-LIKE STAR exhausts its nuclear fuel, it swells into a red giant and eventually puffs off its outer layers. The Helix Nebula is a nearby example. After about 100,000 years, the expanding shell will become too tenuous to see. All that will be left is a faint white dwarf — the eventual fate of the Sun and most other stars with up to 8 solar masses.

NASA AND THE HUBBLE HERITAGE TEAM (STScI/AURA)

THE TATTERED REMAINS of a massive star rush outward in the supernova remnant N 49. The heavy elements forged by the progenitor star get blasted into space, where they eventually will be the raw material for a new generation of stars. That's how the Sun and its planets acquired heavy elements like gold and silver. After the explosion, the star's collapsed core ends up either as a neutron star or black hole.

/// THE 25 NEAREST STAR SYSTEMS

Name	R. A.	Dec.	Mag.	Abs. mag.	Spectral type	Luminosity class	Distance
Proxima Centauri	14h29.7m	−62°41'	11.05	15.5	M5.5	V	4.22
Alpha Centauri*	14h39.6m	−60°50'	−0.29	4.1	G2	V	4.36
Barnard's Star	17h57.8m	4°42'	9.54	13.2	M4	V	5.96
Wolf 359	10h56.5m	7°01'	13.54	16.7	M5.5	V	7.78
Lalande 21185	11h03.3m	35°58'	7.49	10.5	M2	V	8.29
Sirius*	6h45.1m	−16°43'	−1.47	1.4	A1	V	8.58
UV Ceti*	1h39.0m	−17°57'	12.52	15.4	M5.5	V	8.72
Ross 154	18h49.8m	−23°50'	10.95	13.6	M3.5	V	9.68
Ross 248	23h41.9m	44°11'	12.28	14.8	M5.5	V	10.3
Epsilon Eridani	3h32.9m	−9°27'	3.73	6.2	K2	V	10.5
Lacaille 9352	23h05.9m	−35°51'	7.34	9.8	M0.5	V	10.7
Ross 128	11h47.7m	0°48'	11.08	13.5	M4	V	10.9
EZ Aquarii*	22h38.6m	−15°18'	12.18	14.5	M5.5	V	11.3
Procyon*	7h39.3m	5°13'	0.34	2.6	F5	IV–V	11.4
61 Cygni*	21h06.9m	38°45'	5.21	7.5	K5	V	11.4
Gliese 725*	18h42.8m	59°38'	8.91	11.2	M3	V	11.5
Gliese 15*	0h18.4m	44°01'	8.07	10.3	M1.5	V	11.6
Epsilon Indi*	22h03.4m	−56°47'	4.69	6.9	K4.5	V	11.8
DX Cancri	8h29.8m	26°47'	14.81	17.0	M6	V	11.8
Tau Ceti	1h44.1m	−15°56'	3.50	5.7	G8	V	11.9
Gliese 1061	3h36.0m	−44°31'	13.03	15.2	M5.5	V	12.0
YZ Ceti	1h12.5m	−17°00'	11.60	13.7	M4.5	V	12.1
Luyten's Star	7h27.4m	5°14'	9.89	12.0	M3.5	V	12.4
SO 0253–1652	2h55.2m	16°17'	15.40	17.5	M7	V	12.5
Kapteyn's Star	5h11.7m	−45°01'	8.89	10.9	M1	V	12.8

* Stars with more than one component. Magnitudes combine all components; spectral types just the brightest member. Most astronomers think Proxima Centauri is an outlying member of the Alpha Centauri system.

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/// STELLAR SPECTRAL CLASSES

Spectral class	color	Surface temperature (Kelvin)	Main sequence mass (Sun=1)	Main sequence radius (Sun=1)	Lifetime (years)	Examples
O	blue	greater than 31,000	20–120	12–25	less than 6 million	Zeta Puppis
B	blue-white	10,000–31,000	4–20	4–12	6–300 million	Rigel, Spica
A	white	7,400–10,000	2–4	1.5–4	300 million–1.8 billion	Sirius, Vega
F	yellow-white	6,000–7,400	1.05–2	1.1–1.5	1.8–8.8 billion	Canopus, Procyon
G	yellow	5,300–6,000	0.8–1.05	0.85–1.1	8.8–17 billion	Sun, Capella
K	orange	3,900–5,300	0.5–0.8	0.6–0.85	17–55 billion	Aldebaran, Arcturus
M	red	2,200–3,900	0.08–0.5	0.1–0.6	55 billion–5.5 trillion	Antares, Betelgeuse