SCOPE
On the skies

Star bright

During the latter half of the nineteenth century, astronomers studied stars and devised an alphabetical method for classifying stars by chemical composition. This system was based in large part on the work of Angelo Secchi, a Roman Catholic priest, who in the 1860s studied the spectra of hundreds of stars using a prism placed in front of a telescope. During the 1870s Henry Draper, an American amateur astronomer, elaborated on Secchi's objective prism technique and photographed the spectra of many stars. After Draper died, his wife endowed Harvard University with money to create a stellar spectroscopy department to continue his work.

Harvard's new department, led by Edward Pickering, published a catalog listing the spectral descriptions of more than 10,000 stars, which was based on the work of Williamina Fleming. The catalog's system of arranging stars alphabetically from A to N was somewhat based on the chemical classification system Secchi devised. At about the same time, Antonia Maury, Henry Draper's niece, joined the department. Working only with spectra from bright stars, she reclassified stars into a sequence of three groups ranging from stars with very narrow spectral lines to those with very wide spectral lines. An important result of her studies, significant especially to Ejnar Hertzsprung and the development of the H-R diagram, was the correlation between thin spectral lines and giant stars. Hertzprung was looking for a way to distinguish main sequence stars (stars within the relatively stable midlife period of the life cycle) from giant stars (stars near the end of their lives).

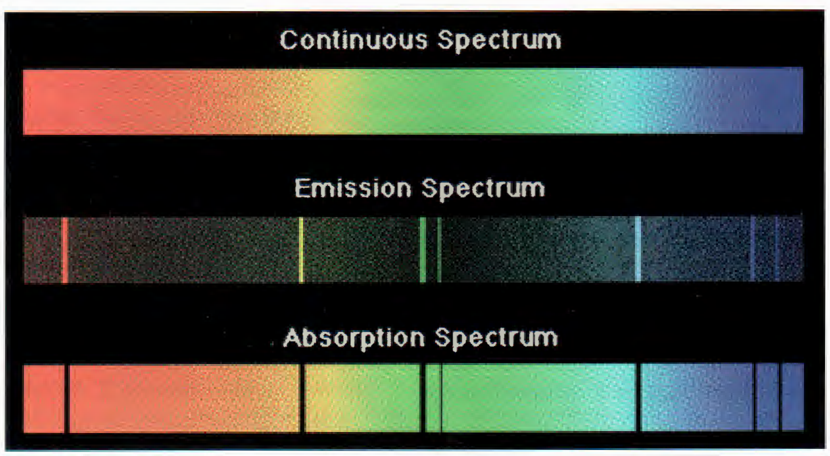
However, the work of Annie J. Cannon probably contributed most toward the development of the H-R diagram. After joining the department in 1896, she began a rigorous program of examining the spectra of even more stars. Cannon arranged the order of the letters describing stellar chemical composition to classify stars by spectral class. She became so adept at identifying stellar spectra that she was able to add subclasses of spectra between each letter. The letters O, *B*, *A*, *F*, G, *K*, and M (the order of which may be remembered by the mnemonic phrase Oh Be A Fine Girl Kiss Me) describe the temperature ranges, with class O stars the hottest and M the coolest.

What H-R diagrams tell us

In the H-R diagram, representations of stars are plotted on a graph with the vertical axis representing the star's luminosity (actual brightness) and the horizontal axis describing its spectral class (temperature). The resulting arrangement of stars indicates the relationship between the luminosity of a star and its spectral class. The brighter, hotter stars appear at the top left, and the dimmer, cooler stars at the bottom right portion of the diagram. Stars of a certain spectral class tend to lie within a distinct range of luminosities because larger stars, which have more surface area, tend to be brighter. The stars' colors, which overlap the spectral class designations somewhat, range from blue (the hottest) through to the increasingly cooler white, yellow, orange, and red stars (the coolest).

All stars have a life cycle that varies depending mostly on its initial mass. The H-R diagram suggests not only the evolutionary trail a star follows as it progresses through its various life stages, but also where it will be in the future. The location of a star on the H-R diagram indicates the star's current stage of development. For example, our Sun, like most other stars, lies along an area of the diagram known as the *main sequence*. Currently, the Sun is in its midlife; the length of a star's midlife depends on the star's mass.

However, some stars either have not yet reached or have progressed beyond the main sequence. Therefore, a star's mass, which is not shown on the H-R diagram, is actually the deciding factor in determin-



A comparison of the full visible electromagnetic radiation spectrum, emission spectrum, and absorption spectrum

An image of the Eagle Nebula, a star-forming gas and dust cloud, captured by the Hubble Space Telescope

ing its spectral class. In order for a star to have a particular temperature and luminosity, it must have a certain mass. Because we are most familiar with Sol, our Sun, it is routinely used as a standard for reference with other stars. The Sun is a G2, Population I (younger) star. If you examine an H-R diagram, you will find that the most massive, hottest stars are located in the upper-left quadrant of the diagram and the least massive, coolest stars are located in the lower-right quadrant.

If a star is massive enough, the tremendous compression and high temperature caused by the inward gravitational pull of the star's mass, will fuse hydrogen, initially the primary component of most stars. The greater the star's mass, the greater the star's core pressure and temperature, and ultimately, the greater hydrogen's rate of fusion. So bigger stars tend to have hotter surfaces with hues toward the blue end of the light spectrum, and smaller stars tend to have cooler surfaces and hues toward the red end of the spectrum.

It's a star's life

Stars fall into two categories based on age: Population II are the older, original stars in our galaxy, and Population I stars are the relatively newer stars such as our Sun. Population I stars are formed when hydrogen mixes with the remains from Population II stars. A star like our Sun has enough mass to maintain hydrogen fusion within its core for some time, about 10 billion years, and stay stable. The Sun's stability in its current stage results from the balance between its inward gravitational forces due to its mass and the outward-directed nuclear forces from the energy created by fusion in its core. A star the size of the Sun remains in this stage of its life cycle the longest.

Eventually, due to a reduced rate of fusion, the inward-outward balance will favor the inward pull of gravity when most of the hydrogen has fused to form helium. At this time, increased compression raises the temperature within the core. Throughout this stage, hydrogen is still being fused, but only in the outer layers of the star surrounding the denser core.

As temperatures continue to rise within the core due to increasing compression, the layers of fusing hydrogen are pushed outward, causing the star's outer surface to expand and grow brighter. At some point core pressures will reach the level at which helium atoms will fuse to form carbon. The star, which is now a red giant, grows stable once more as the outward nuclear pressure from the energy produced by helium fusion is balanced with the inward gravitational pressure from the star's mass.

However, this balance is relatively short-lived as the helium is consumed quickly, varying somewhat depending on the star's mass. Stars more massive than our Sun spend considerably less time at the stage of instability after helium fusion completes, while less massive stars spend more time at this stage. Regardless of its mass, a star at this stage starts undergoing changes as the balance between the outward push from fusion and the inward pull of gravity alternate. Increasing core temperatures cause further expansion of the star's surface, increasing brightness and a period of stability; however, this episode lasts even shorter than before because of the higher core temperatures. Then, if the star has enough mass left, it enters another phase during which it expands and contracts rhythmically as the elements within its core fuse into heavier and heavier elements. Stars fusing heavier elements are known as pulsating variable stars. Eventually, this pattern of fusing heavier and heavier elements ceases as the star reaches its final phases. The episodes of pulsating expansion continue until the star loses so much mass that it is no longer able to sustain the fusion process.

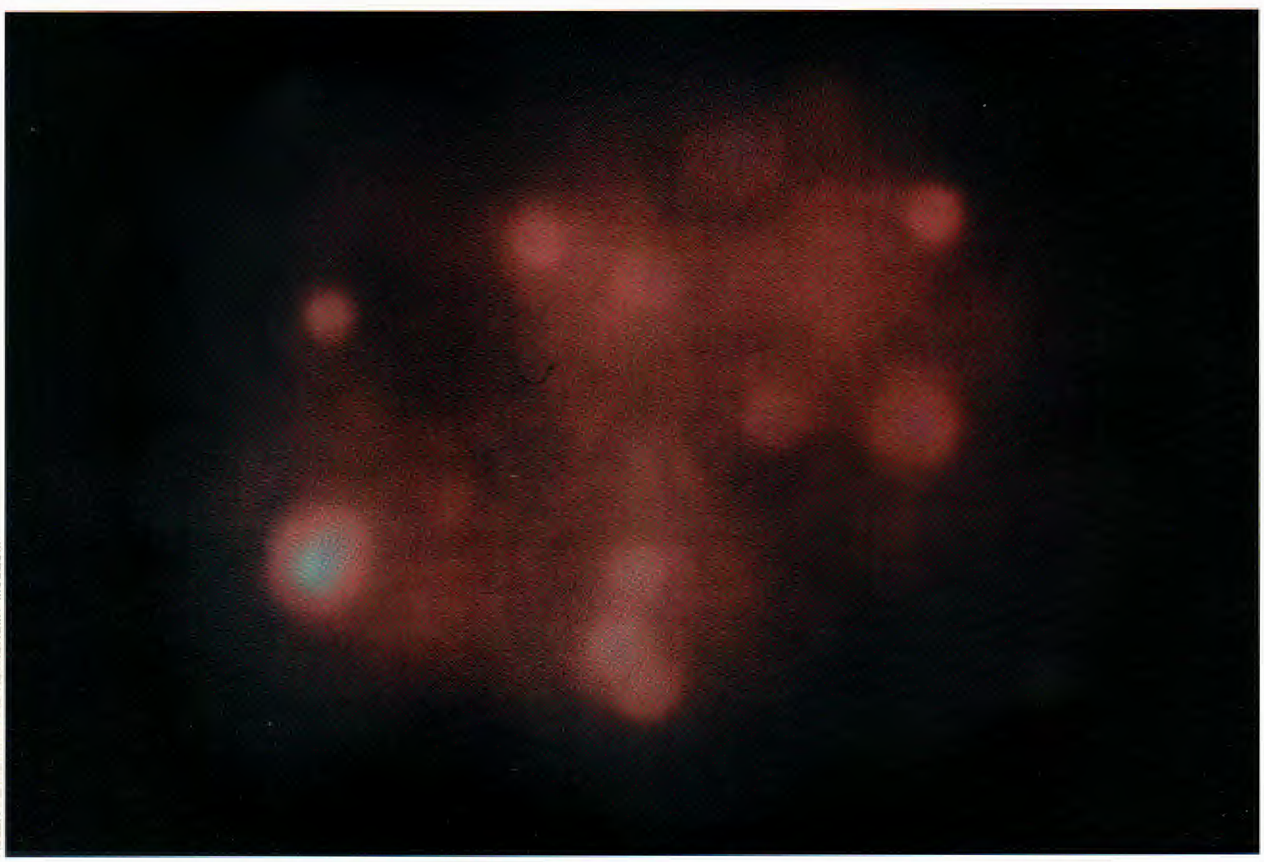
However, the expiring star still has much of its mass and as a result will slowly stop expanding and start collapsing in on itself. This collapse or shrinking continues until the density of the star's core is too great to allow further collapse. At its smaller, more compact size, the star has a bright white surface and is referred to as a *white dwarf*. Then over a very long period of time, the star slowly cools until it no longer radiates energy; the white dwarf star is now a *black dwarf*.

Neutrinos, black holes, supernovas, and more

Stars with less mass than our Sun follow a similar evolution but take more time to evolve. Many unseen stellar objects are floating about in the universe with too little mass to initiate nuclear fusion. Some of these are what we refer to as "soupy" or "gaseous giant planets," such as Jupiter, Saturn, Uranus, and Neptune. Like their stellar counterparts, they also emit radiation but due to the decay of radioactive elements and heat from compression, not from nuclear fusion.

Stars with greater mass than our Sun also follow a similar evolution pattern, but at a much faster rate. In these stars, the fusion process reaches much higher temperatures and pressures, resulting in shorter periods of time for each element to fuse. The accelerated evolution pattern increases the instability of large stars, as it has more episodes of expansion and contraction. The largest stars shed their outer layers and collapse inward many times, creating pressures that allow for the fusion of elements heavier than lead. Somewhere along the way, the balance changes dramatically and much of the star's material is lost, or blasted outward in a violent event known as a *nova* or *supernova*. As with less massive stars, most of the giant star remains and collapses inward, compressing the remaining elements so tightly that protons combine with electrons to form neutrons. The collapse continues until the density is too great, leaving a relatively small and extremely dense, rapidly rotating stellar object composed mostly of neutrons, known as a *neutron star*.

If the large star has enough mass after the supernova event, the inward collapse continues until only an extremely dense object remains—one



ADLER PLANETARY AND ASTRONOMY MUSEUM

An artist's rendition of the formation of a young star cluster with a gravity-induced density so great that the escape velocity from its surface (the speed needed to escape from the object's pull of gravity) is faster than the speed of light. The object has become a *black hole*.

Web resources

- Color plots of the optical emission line spectra of the elements (requires Java)—*www.achilles.net/~jtalbot/data/elements/index.html*
- Timeline of stellar spectroscopy—*www.gsu.edu/other/timeline/stellar.html*
- Bibliographic information: women in astronomy—*www.aspsky.org/html/astro/womenast_bib.html*
- Life cycles of stars—*imagine.gsfc.nasa.gov/docs/teachers/lifecycles/stars.html*

Cosmic events

This year's Draconid meteor shower should peak during the afternoon and evening hours of October 8, although it could peak anytime between October 8 and 10. The Draconids receives its name from its radiant's location near the head of the constellation Draco the Dragon. The constellation is very high over the northwest horizon during the early evening. A cloud of debris weathering off the surface of periodic comet 21P/Giacobini-Zimmer provides the source for the shower. Coincidentally, the comet will reach perihelion (when it's closest to the Sun) during November. As a result, the Earth will pass through fairly recently deposited comet debris, increasing the number of meteors or shooting stars seen during the peak times.

Visible planets

Mars: Rises after midnight and is visible over the southern horizon at sunrise.
Jupiter: Visible over the eastern horizon at sunset, sets before sunrise.
Saturn: Rises at about sunset and is visible all night; sets at sunrise.

Moon phases

October
Full Moon - October 5
Third Quarter - October 12
New Moon - October 20
First Quarter - October 28

November
Full Moon - November 4
Third Quarter - November 11
New Moon - November 19
First Quarter - November 27

Timekeeping reminder

Remember to *fall* back. On the last Sunday in October, October 25, set your clocks back one hour to return to standard time.

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