STARS AND THE MILKY WAY

• Fr. CHRISTOPHER CORBALLY s.j. •

The Census of the Stars

When we are well away from a town or city and look up at the night sky, we can be overwhelmed by the myriads of stars over us. Through a telescope, the sight can be even more inspiring. But how can we find out more about the personalities of these stars?

Everything we know about stars we have learned from their light which gratuitously falls on the Earth. It was Newton who discovered that light can be split up by a prism. He did this for our nearest star, the Sun, and found he was looking at the colours of the rainbow.

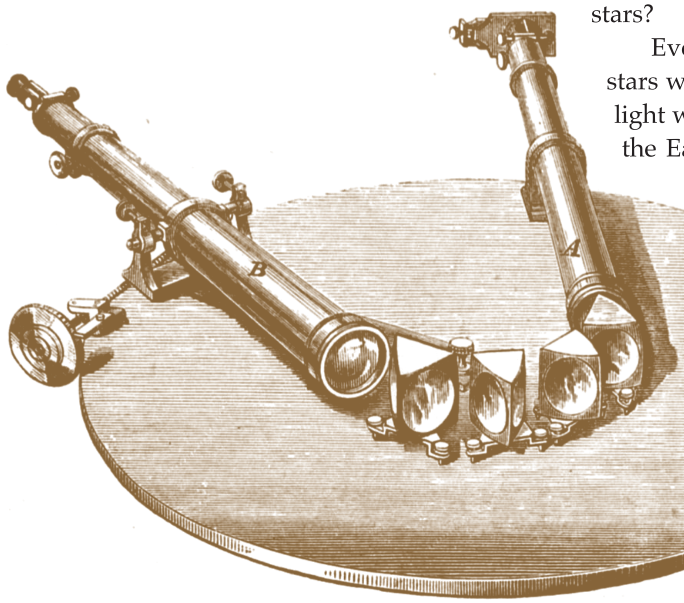
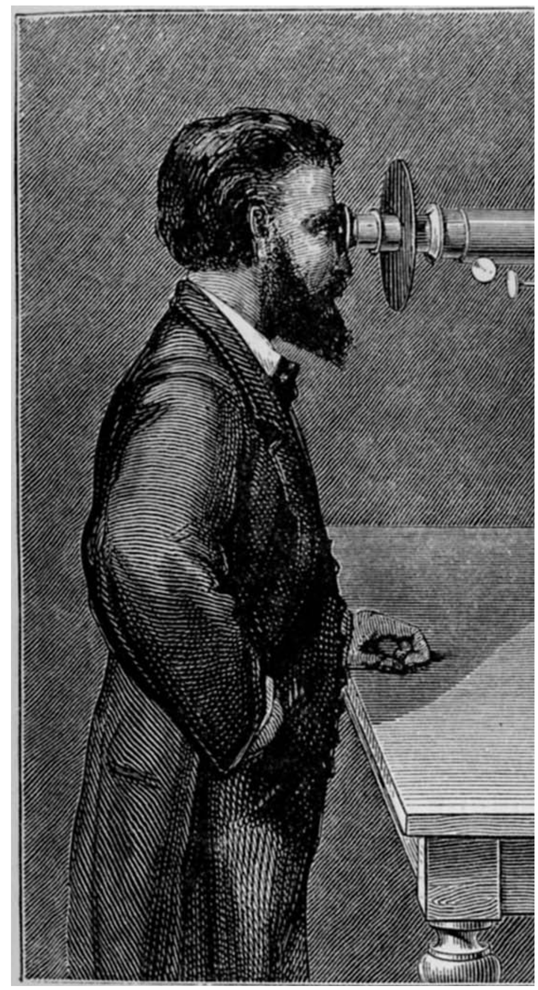


FIG. 47.—Steinheil's form of four-prism spectroscope. A, collimator; B, observing telescope.



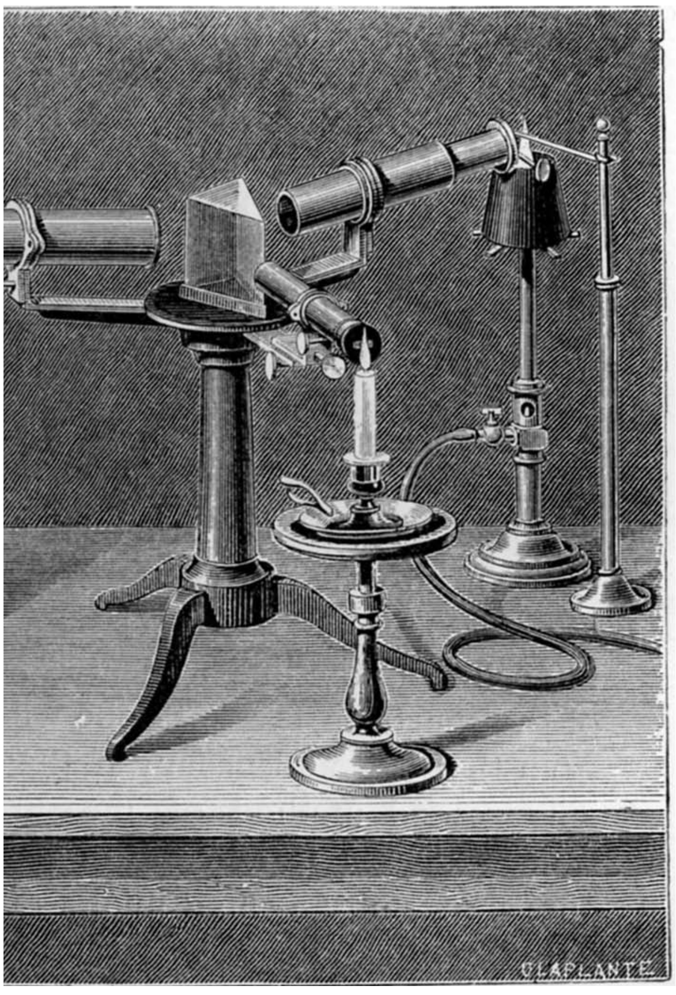
Now these colours are beautiful, but the really interesting details contained within a rainbow, or "spectrum", are revealed when light from a star is focused onto a narrow slit, from there passes though a prism, and then gets focused again onto your eye or a camera.

Left and above *Diagrams of 19th century spectroscopes, taken from J. N. Lockyear,* Contributions to Solar Physics, *published in London by MacMilland and Co. in 1894. This book was a gift to the Specola Vaticana from William Lockyear, inscribed February 1932.*

Above Edward Pickering stands in a room filled with his "computers" who are classifying stars and producing the Harvard College catalogues. Also standing, in the middle, is Williamina Fleming, while Annie Jump Cannon on the right peers at spectra through a microscope. The photo was taken in 1892, and is courtesy of the Harvard College archive.

A History of Stellar Spectra

Josef von Fraunhofer first split up the light from a star in 1814. At first he had a tiny telescope so he could only look at the brightest star in the night sky, Sirius. Later he used a larger telescope and observed more stars. But of course the Sun as the very brightest "star" gave him the best spectrum in which he was able to see the dark "lines" where light was missing from the rainbow.



Later it was understood why some of the light was missing. While all the colours of the rainbow are made in the interior of the Sun, its atmosphere, being cooler than the interior, absorbs the out-streaming light at very specific colours, or wavelengths, that correspond to the atoms and molecules there. Each atom or molecule has, as it were, its own unique "fingerprint" in which the strengths of the features corresponds with the particular conditions of temperature and pressure of the gas making that fingerprint or pattern of lines. So the spectrum of a star tells us what is in its atmosphere, and how hot and big the star is.

It took nearly 50 years after Fraunhofer observed the first stellar spectrum for the next big breakthrough. In 1863, Giovanni Battista Donati (Italy), George Airy, William Huggins (both in England), Lewis M. Rutherfurd (United States), and Father Angelo Secchi (Vatican) each published pioneering papers on their observations of stars through a spectrograph. Our knowledge of stars really took off from that time!

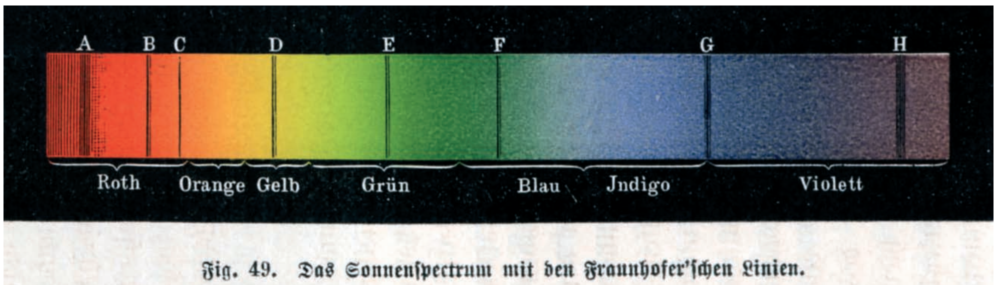
Father Secchi, after travels in the United States, returned to Italy and became director of the Roman College Observatory, the predecessor to the current Vatican Observatory. Besides spectroscopy, his wide interests covered meteorology, terrestrial magnetism, sunspots and other solar chromospheric phenomena, double stars and comets. By the end of his life he had sorted over 4,000 stars according to their spectra. He arranged them into four classes, and he thought about the differences in physical conditions that would be bringing about the differences he was seeing in their spectra. While Huggins might be regarded as the founder of stellar spectroscopy, Secchi's pure and prolific approach makes him the father of stellar spectral classification, along with the branches of astrophysics that his methods encouraged.

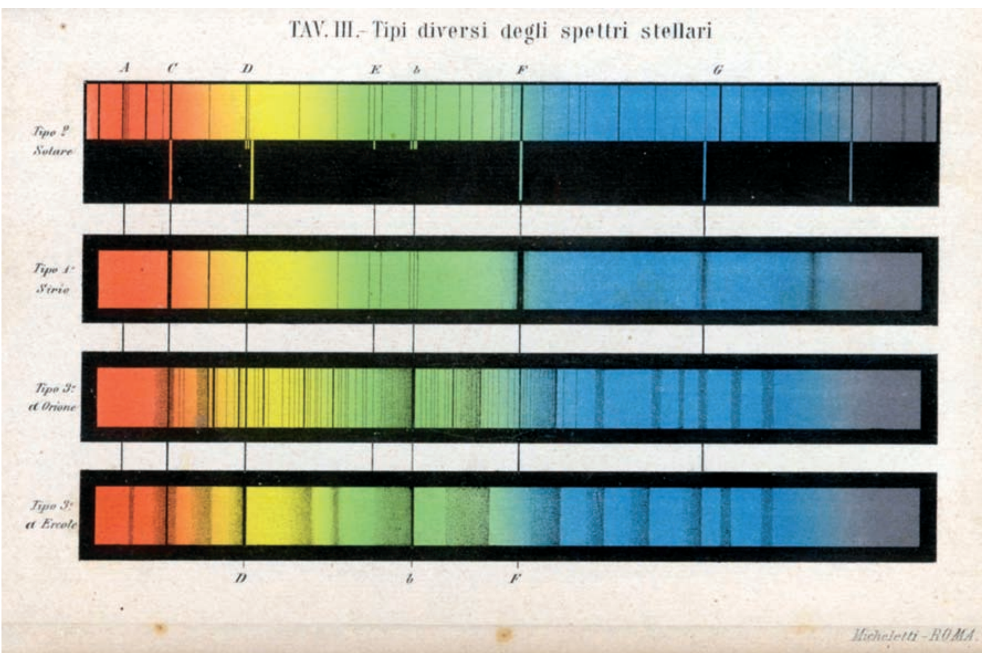
The sorting of stars according to their spectra continued to be refined through such as Hermann Carl Vogel's work in Germany, first in Bothkamp and then Potsdam. From 1885 and for the next four decades, a major centre of spectral classification was the Harvard College Observatory in Cambridge Massachusetts. There, the energetic director, Edward C. Pickering, encouraged the sharp eyes and expertise of Williamina Fleming, Antonia Maury, and Annie Jump Cannon, with their fellow "computers" (as these assistants were called), to produce huge catalogues of stars. So dedicated was Cannon that by the end of her life she had classified over 395,000 stars in the "Draper system" of the Harvard College Observatory, which not surprisingly had become the internationally accepted system at the first General Assembly of the International Astronomical Union in Rome in 1922.

Spectra and Brightness

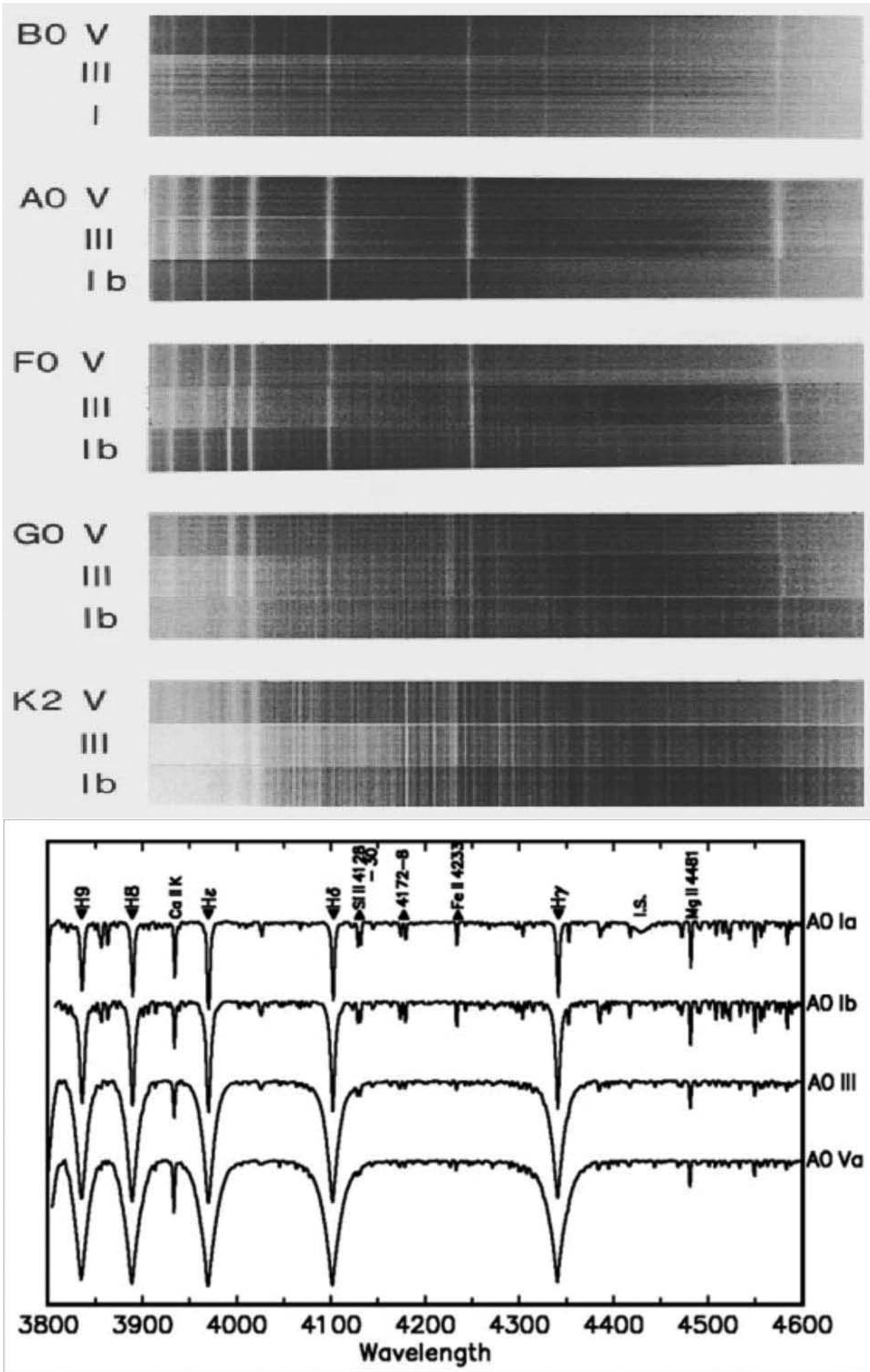
In the 1920s Walter Adams and Arnold Kohlschütter, while working at the Mt. Wilson Observatory in California, noticed that besides changes with temperature, some spectral features changed depending on the overall size and so brightness of the star while other features did not. The ratio of the changing to the unchanging features, or "lines," allowed a calibration of such ratios with the star's actual brightness. And knowing how bright a star actually is, its "absolute brightness," and also how bright it appears to us, gives a measure of the star's distance away from us. (Just as knowing at night whether it is a torch or a searchlight shining at you gives you an idea of how far away it is.) Hence was born the technique of "spectroscopic parallaxes" or distances to stars. With that, we can plot out how different stars in our Milky Way galaxy are distributed. When it was also realized that the very hottest stars were the youngest, one could pinpoint the regions in our galaxy where stars have most recently been formed. "Galactic structure" work was now possible, leading to an understanding of what kind of stars make up our Milky Way, particularly in its spiral arms, and so outline our Galaxy's history.

Obviously, the better one could pin down the luminosity of a star, the better that Galactic structure work would become. The team of William W. Morgan and Philip C. Keenan, while together at Yerkes Observatory in Wisconsin, so carefully refined the way in which stars of different surface tem-





Top *The Sun's spectrum with the Fraunhofer Lines. These dark features show where light is missing from the full rainbow of colours due its absorption by atoms and molecules in the outer atmosphere of the Sun.* ***Bottom*** *Father Angelo Secchi's drawings of "Different Types of Stellar Spectra" are from his by-eye observations of four bright stars. The top one, of the Sun, illustrates his spectral class 2 and it is marked with features first labelled by Fraunhofer. The next, class 1, is illustrated by Sirius, the hottest star in this picture. The two spectra at the bottom are both of class 3, but α Herculis (Rasalgethi) is a bit cooler than α Orionis (Betelgeuse) and so has banded features that are more pronounced. These bands are due to titanium oxide molecules. Secchi's fourth class is not illustrated here but he deduced that its bands of 'reversed intensity' were due to carbon molecules. Rasalgethi and Betelgeuse are huge, supergiant stars, while the Sun and Sirius are regular-sized stars, called dwarfs in comparison.*



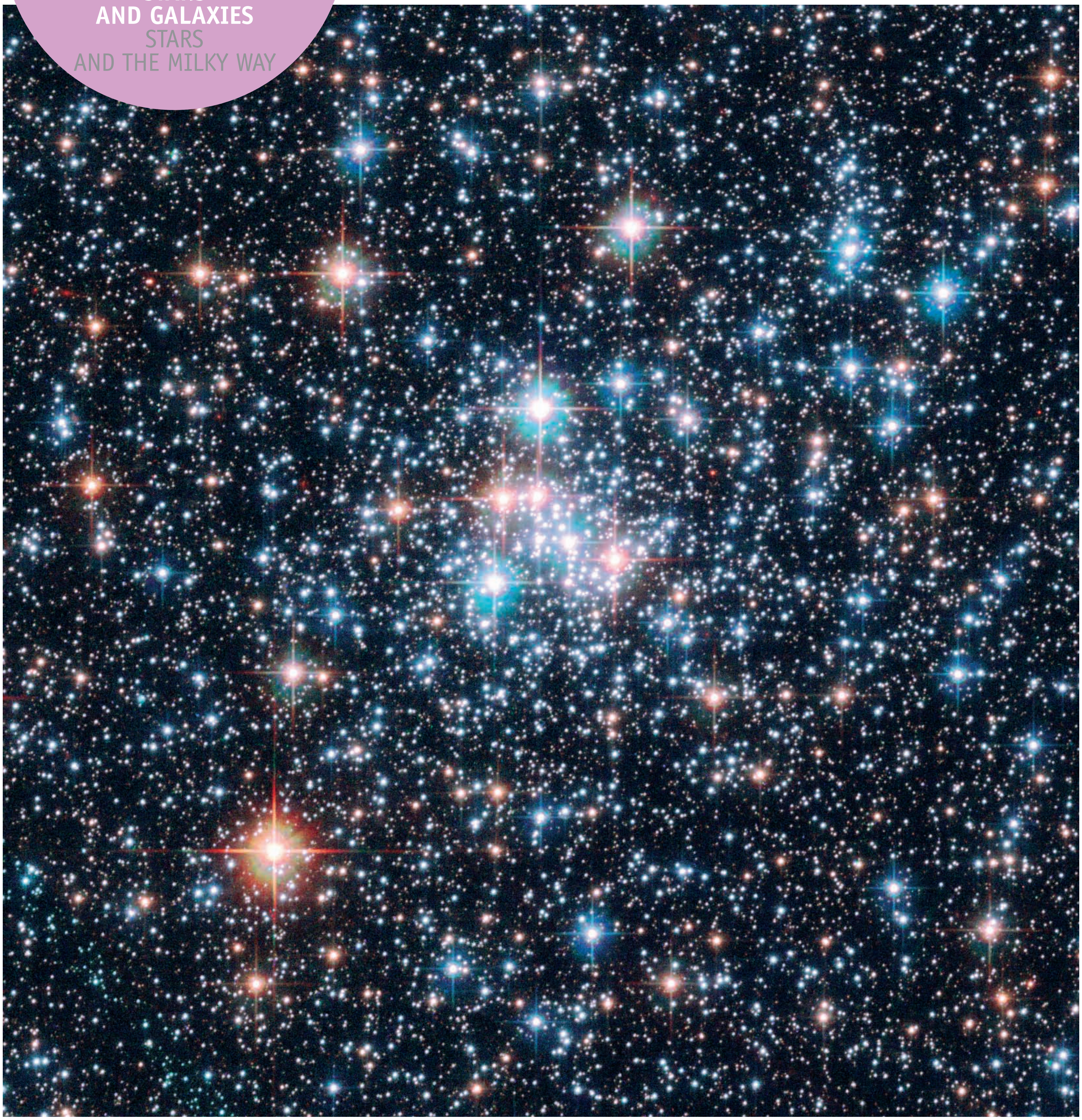
Above *Sets of spectra of stars with different brightness, ranging from the dwarfs "V", through the giants "III", to the supergiants "Ia or Ib". Above are the classic photographic spectra, shown as negatives. Notice how from the set of hottest "B" stars at the top to the coolest "K" stars at the bottom, it is the change in temperature that makes the difference in appearance, for the amount of the elements in their atmospheres (hydrogen, helium, carbon, iron, etc.) does not change.*
Below are spectra observed with a modern digital detector. Their downwards directed "teeth" correspond to the light lines in the photographic spectra and are for a set of "A0" temperature stars, like the second set in the photographic spectra above. Many people find the details in the digital spectra clearer than in the photographic ones, and certainly one can now reach fainter stars with digital detectors.

perature could be classified into their respective luminosities that this "MK system" with its unchanging lists of standard stars is still the way in which it is done today. In producing their beautiful atlas of spectra, showing the effects of luminosity, they were helped by Edith Kellman; their definitive work published in 1943 is known as the MKK Atlas.

It happened that a full thirteen of the MKK Atlas's printed plates of spectra showed stars that had peculiarities in relation to the normal run of stars. So it was clear even then that further refinements were needed to the MK System. This identification of peculiarities and the attempt to discover the physical reasons for them has become the bread-and-butter work of many stellar spectral classifiers since then.

Classifying Stars

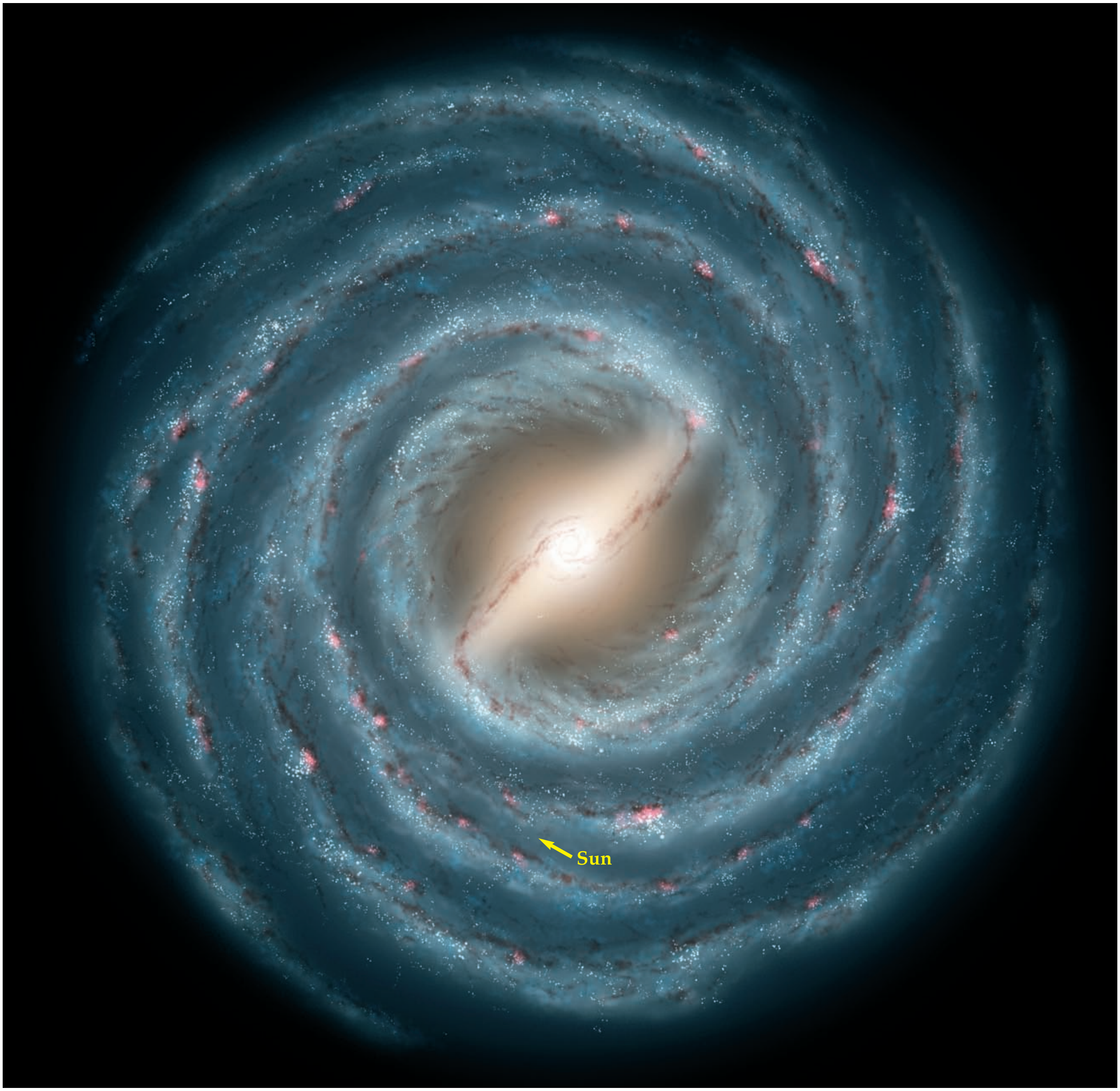
Classifying stars is a bit like classifying people. At sufficient distance everyone looks the same. Closer, and one sees the major differences between them and one can sort them into classes depending on height, apparent age, colour of skin, and prominent features. Very close up, and everyone is different. The trick for classifying star spectra is to get sufficient detail for a general description of a spectrum while not being



Above *Hubble Space Telescope image of the star cluster NGC290.*
The bluest stars are the hottest;
the bright reddish stars have evolved beyond their "middle age" period into red giant stars. Yellowish stars like our Sun are among the fainter ones.
Credit: *European Space Agency & NASA*
Acknowledgment: *E. Olszewski (University of Arizona)*

overwhelmed by the differences between the spectra. Morgan and Keenan got this "right distance," or spectral resolution, perfect for stars.

They also used spectra that showed the blue-green region of the spectral rainbow. This was because their photographic emulsions were the most sensitive in this spectral region, but it also turns out that the "fingerprints" of atoms and molecules vary the most strongly there with small differences in the temperatures and pressures of the stellar atmospheres. Modern work in stellar classification has taken advantage of the different spec-



tral regions that new detectors and observing possibilities from satellites have brought. So the ultraviolet, available only in space, is best for studying stars with huge winds blowing from their surfaces or for identifying the hot companion of a twin star system; the infrared will work best for objects that are very cool, like "brown dwarfs," or for stars that are embedded in giant clouds of dust that blocks the bluer light from getting out to us.

Above *Blue stars tend to be young stars, and so they are most likely to be found in the spiral arms of a galaxy. The distribution of young star clusters and individual blue giant stars within our own Milky Way Galaxy, as deduced from their known brightness and so distances, can be used to map out a the picture of our galaxy, shown here as if viewed from the "top."*
Credit: *NASA/JPL-Caltech/R. Hurt (SSC)*

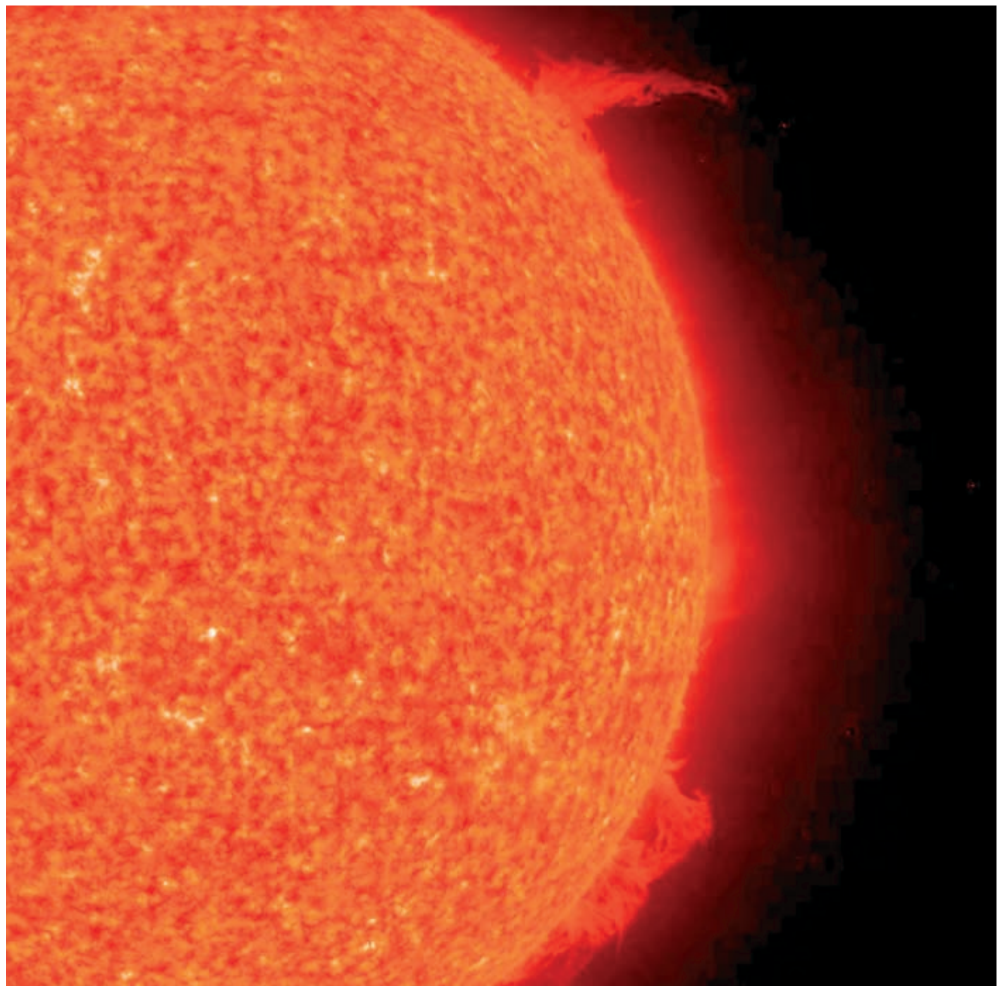
Getting to Know Our Neighbors

We have seen how the spectral classification of stars helps us map out the distant structure of our Milky Way galaxy. It also helps us get to know our neighbours. And you never know, we might find some that are intelligent! This was the thinking behind the Nearby Stars census of NASA, in which the Vatican Observatory participated. Through spectral classification of all the stars near us, and then comparing their spectra with computer-generated models of star spectra, we can draw up a list of our neighbourhood stars which are most like our Sun. Since we know that the conditions which formed our Sun were also suitable to form our planets, the expectation is that these solar-like stars, which we picked out, could also have their own planets around them.

"Most like" also includes the idea that a star has an activity level like our Sun. Young children have bundles of energy, while an adult generally moves more sedately; similarly, a mature star like our own has slowed down from its initial high speed of rotation and so its surface activity has quietened, though solar flares and prominences can still be impressive on our current Sun. High solar activity in the past generated energetic particles that hit the Earth and made things more difficult for life to form, so the thinking goes. If we are looking for a planet with life around another star, then the less active that star the better the chance we have of success.

The Simple Picture Gives Way to Surprises

We often start with simple pictures of how things work, and then begin to find the complications. The same is true for our picture of the Milky Way. We have mentioned how its spiral structure shows where stars have recently been formed. In the central, nuclear bulge of the Milky Way are the older stars, including a monster black-hole that has been living happily on a diet of stars that it manages regularly to suck into itself. In the outer halo of the Milky Way, extending from both sides of the relatively flat spiral struc-



Above *The limb of our Sun in extreme ultraviolet light emitted by ionized Helium, an element which was first discovered in the Sun. The flaring of the prominence and the glow from its outer atmosphere shows its amazing activity. Yet compared with younger stars, this activity is quite low. The recent Census of Nearby Stars measured the activity level of our neighbouring stars. Those with low activity are presumed most likely to favour life on any earth-like planets they would have.*
Credit: *STEREO Project, NASA*

ture of the disk, were found the remnants of the initially spherical galaxy before it collapsed down into a slowly spinning disk. These remnants included globular clusters of stars as well as individual, free-moving stars.

As astronomers were able to find and probe the character of fainter and fainter stars out in the Milky Way's halo, it became clear that collections of these stars formed streams, all moving together through the halo. Where were they coming from? It was realised that these streams of stars are remnants of our own Milky Way's collisions with other, smaller galaxies. This more complicated picture, which we shall explore in the following chapters, of galaxies interacting with each other rather than staying isolated universes, has its traces in the faintest structures of our own Milky Way. When we get to know stars though their spectra, there are always surprises waiting for us.

Above *The Star Streams of NGC 5907.*
This "Knife Edge" galaxy is surrounded by ghostly streams of stars.
They have come from a smaller, "dwarf galaxy" whose stars were gradually torn apart from each other in its encounter with NGC 5907, some four billion years ago.
Image courtesy of R Jay Gabany (Blackbird Observatory), D.Martínez-Delgado (IAC, MPIA), J.Peñarrubia (U.Victoria), I.Trujillo (IAC), S.Majewski (U.Virginia), M.Pohlen (Cardiff).

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This chapter, based on that work, was written specially for this book.