

# Hertzsprung–Russell diagram

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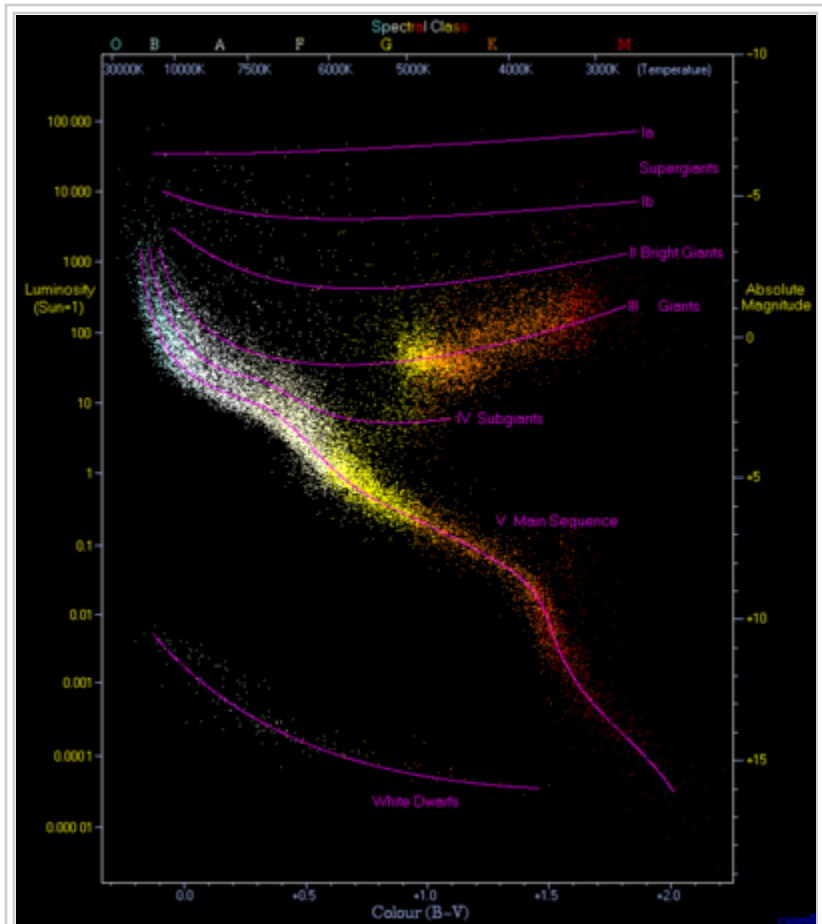
The **Hertzsprung–Russell diagram** is a scatter graph of stars showing the relationship between the stars' absolute magnitudes or luminosities versus their spectral types or classifications and effective temperatures.

Hertzsprung–Russell diagrams are *not* maps of the locations of the stars. Rather, they plot each star on a graph measuring the star's absolute magnitude (brightness) against its temperature (color).

Hertzsprung–Russell diagrams are also referred to by the abbreviation **H–R diagram** or **HRD**. The diagram was created circa 1910 by Ejnar Hertzsprung and Henry Norris Russell and represents a major step towards an understanding of stellar evolution or "the lives of stars".

## Contents

- 1 Historical background
- 2 Forms of diagram
- 3 Interpretation
- 4 Diagram's role in the development of stellar physics
- 5 See also
- 6 References
  - 6.1 Bibliography
- 7 External links



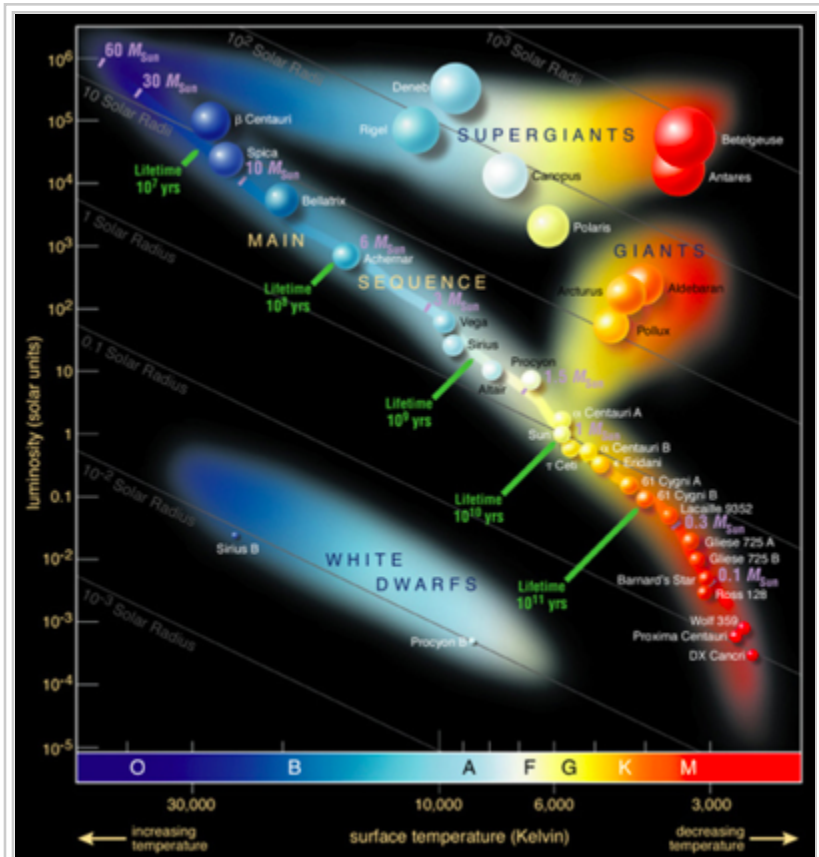
Hertzsprung–Russell diagram<sup>[1]</sup> with 22,000 stars plotted from the Hipparcos Catalogue and 1,000 from the Gliese Catalogue of nearby stars. Stars tend to fall only into certain regions of the diagram. The most prominent is the diagonal, going from the upper-left (hot and bright) to the lower-right (cooler and less bright), called the main sequence. In the lower-left is where white dwarfs are found, and above the main sequence are the subgiants, giants and supergiants. The Sun is found on the main sequence at luminosity 1 (absolute magnitude 4.8) and B–V color index 0.66 (temperature 5780 K, spectral type G2V).

## Historical background

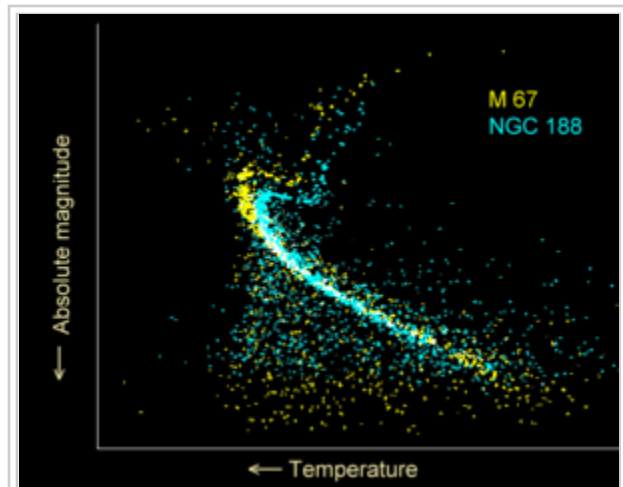
In the late 19th century large-scale photographic spectroscopic surveys of stars were performed at Harvard College Observatory, producing spectral classifications for tens of thousands of stars, culminating ultimately in the Henry Draper Catalogue. In one segment of this work<sup>[2]</sup> Antonia Maury included divisions of the stars by the width of their spectral lines. Hertzsprung noted that stars described with narrow lines tended to have smaller proper motions than the others of the same spectral classification. He took this as an indication of greater luminosity for the narrow-line stars, and computed secular parallaxes for several groups of these, allowing him to estimate their absolute magnitude.<sup>[3]</sup> All these supergiant stars are too distant for meaningful parallaxes to have been measured before the advent of space astrometry, so no estimate of their absolute magnitude existed prior to that work. Russell's early (1913) versions of the diagram included these supergiants, those nearby stars with parallaxes measured at the time, and stars from the Hyades (a nearby open cluster), and several moving groups, for which the moving cluster method could be used to derive distances and thereby obtain absolute magnitudes for those stars.<sup>[4]</sup>

## Forms of diagram

There are several forms of the Hertzsprung–Russell diagram, and the nomenclature is not very well defined. All forms share the same general layout: stars of greater luminosity are toward the top of the diagram, and stars with higher surface temperature are toward the left side of the diagram.



An HR diagram showing many well known stars in the Milky Way galaxy.



HR diagrams for two open clusters, M67 and NGC 188, showing the main-sequence turn-off at different ages.

The original diagram displayed the spectral type of stars on the horizontal axis and the absolute visual magnitude on the vertical axis. The spectral type is not a numerical quantity, but the sequence of spectral types is a monotonic series ordered by stellar surface temperature. Modern observational versions of the chart replace spectral type by a color index (in diagrams made in the middle of the 20th Century, most often the B-V color) of the stars. This type of diagram is what is often called an observational Hertzsprung–Russell diagram, or specifically a **color-magnitude diagram (CMD)**, and it is often used by observers. In cases where the stars are known to be at identical distances such as with a star cluster, the term color-magnitude diagram is often used to describe a plot of the stars in the cluster in which the vertical axis is the apparent magnitude of the stars: for cluster members, by assumption there is a single additive constant difference between apparent and absolute magnitudes (the distance modulus) for all stars. Early studies of nearby open clusters (like the Hyades and Pleiades) by Hertzsprung and Rosenberg<sup>[5]</sup> produced the first CMDs, antedating by a few years Russell's influential synthesis of the diagram collecting data for all stars for which absolute magnitudes could be determined.<sup>[6][7]</sup>

Another form of the diagram plots the effective surface temperature of the star on one axis and the luminosity of the star on the other, almost invariably in a log-log plot. Theoretical calculations of stellar structure and the evolution of stars yield these quantities directly. This type of diagram could be called *temperature-luminosity diagram*, but this term is hardly ever used; when the distinction is made, this form is called the *theoretical Hertzsprung–Russell diagram* instead. A peculiar characteristic of this form of the H–R diagram is that the temperatures are plotted from high temperature to low temperature, which aids in comparing this form of the H–R diagram with the observational form.

Although the two types of diagrams are similar, astronomers make a sharp distinction between the two. The reason for this distinction is that the exact transformation from one to the other is not trivial. To go between effective temperature and color requires a color-temperature relation, and constructing that is difficult; it is known to be a function of stellar composition and can be affected by other factors like stellar rotation. When converting luminosity or absolute bolometric magnitude to apparent or absolute visual magnitude, one requires a bolometric correction, which may or may not come from the same source as the color-temperature relation. One also needs to know the distance to the observed objects (*i.e.*, the distance modulus) and the effects of interstellar obscuration, both in the color (reddening) and in the apparent magnitude (extinction). For some stars, circumstellar dust also affects colors and apparent brightness. The ideal of direct comparison of theoretical predictions of stellar evolution to observations thus has additional uncertainties incurred in the conversions between theoretical quantities and observations.

## Interpretation

Most of the stars occupy the region in the diagram along the line called the main sequence. During that stage stars are fusing hydrogen in their cores. The next concentration of stars is on the horizontal branch (helium fusion in the core and hydrogen burning in a shell surrounding the core). Another prominent feature is the Hertzsprung gap located in the region between A5 and G0 spectral type and between +1 and −3 absolute magnitudes (*i.e.* between the top of the main sequence and the giants in the horizontal branch). RR Lyrae variable stars can be found in the left of this gap. Cepheid variables reside in the upper section of the instability strip.

The H-R diagram can also be used by scientists to roughly measure how far away a star cluster is from Earth. This can be done by comparing the apparent magnitudes of the stars in the cluster to the absolute magnitudes of stars with known distances (or of model stars). The observed group is then shifted in the vertical direction, until the two main sequences overlap. The difference in magnitude that was bridged in order to match the two groups is called the distance modulus and is a direct measure for the distance. This technique is known as *main-sequence fitting* or *spectroscopic parallax*.

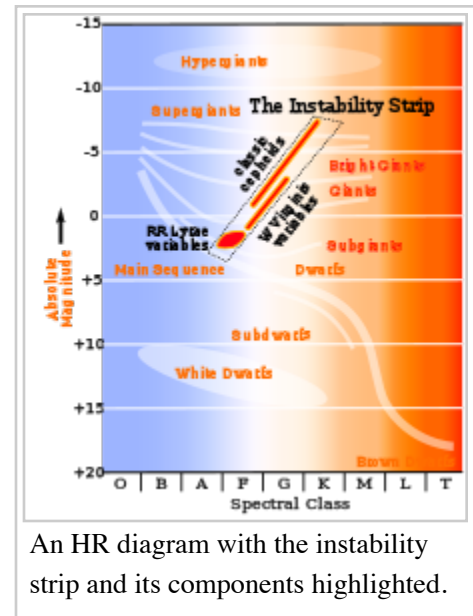
## Diagram's role in the development of stellar physics

Contemplation of the diagram led astronomers to speculate that it might demonstrate stellar evolution, the main suggestion being that stars collapsed from red giants to dwarf stars, then moving down along the line of the main sequence in the course of their lifetimes. Stars were thought therefore to radiate energy by converting gravitational energy into radiation through the Kelvin–Helmholtz mechanism. This mechanism resulted in an age for the Sun of only tens of millions of years, creating a conflict over the age of the Solar System between astronomers, and biologists and geologists who had evidence that the Earth was far older than that. This conflict was only resolved in the 1930s when nuclear fusion was identified as the source of stellar energy.

However, following Russell's presentation of the diagram to a meeting of the Royal Astronomical Society in 1912, Arthur Eddington was inspired to use it as a basis for developing ideas on stellar physics.<sup>[8]</sup> In 1926, in his book *The Internal Constitution of the Stars* he explained the physics of how stars fit on the diagram. This was a particularly remarkable development since at that time the major problem of stellar theory, the source of a star's energy, was still unsolved. Thermonuclear energy, and even that stars are largely composed of hydrogen (see metallicity), had yet to be discovered. Eddington managed to sidestep this problem by concentrating on the thermodynamics of radiative transport of energy in stellar interiors.<sup>[9]</sup> So, Eddington predicted that dwarf stars remain in an essentially static position on the main sequence for most of their lives. In the 1930s and 1940s, with an understanding of hydrogen fusion, came a physically based theory of evolution to red giants, and white dwarfs. By this time, study of the Hertzsprung–Russell diagram did not drive such developments but merely allowed stellar evolution to be presented graphically.

## See also

- Asymptotic giant branch
- Galaxy color–magnitude diagram
- Hayashi track
- Heney track



- Hess diagram
- Red clump
- Stellar birthline
- Stellar classification
- Tip of the red-giant branch
- Color–color diagram

## References

- <sup>^</sup> Richard Powell (<http://www.atlasoftheuniverse.com/hr.html>) with permission.
- <sup>^</sup> A.C. Maury; E.C. Pickering (1897). "Spectra of bright stars photographed with the 11-inch Draper Telescope as part of the Henry Draper Memorial". *Annals of Harvard College Observatory* **28**: 1–128. Bibcode:1897AnHar..28....1M (<http://adsabs.harvard.edu/abs/1897AnHar..28....1M>).
- <sup>^</sup> Hertzsprung, Ejnar (1909). "Über die Sterne der Unterabteilung *c* und *ac* nach der Spektralklassifikation von Antonia C. Maury". *Astronomische Nachrichten* **179** (4296): 373–380. Bibcode:1909AN....179..373H (<http://adsabs.harvard.edu/abs/1909AN....179..373H>). doi:10.1002/asna.19081792402 (<http://dx.doi.org/10.1002%2Fasna.19081792402>).
- <sup>^</sup> Russell, Henry Norris (1914). "Relations Between the Spectra and Other Characteristics of the Stars". *Popular Astronomy* **22**: 275–294. Bibcode:1914PA.....22..275R (<http://adsabs.harvard.edu/abs/1914PA.....22..275R>).
- <sup>^</sup> Rosenberg, Hans (1910). "Über den Zusammenhang von Helligkeit und Spektraltypus in den Plejaden". *Astronomische Nachrichten* **186** (4445): 71–78. Bibcode:1910AN....186...71R (<http://adsabs.harvard.edu/abs/1910AN....186...71R>). doi:10.1002/asna.19101860503 (<http://dx.doi.org/10.1002%2Fasna.19101860503>).
- <sup>^</sup> The first Hertzsprung–Russell diagram (<http://www.leosondra.cz/en/first-hr-diagram/>), Leos Ondra
- <sup>^</sup> Who first published a Hertzsprung–Russell diagram? Hertzsprung or Russell? Answer: neither! ([http://wayback.archive.org/web/20100616094848/http://cosmicdiary.org/blogs/john\\_hearnshaw/?p=583](http://wayback.archive.org/web/20100616094848/http://cosmicdiary.org/blogs/john_hearnshaw/?p=583)), John Hearnshaw, September 2009
- <sup>^</sup> Porter, 2003.
- <sup>^</sup> Smith, 1995.

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## External links

- JavaHRD (<http://www.astro.uni-bonn.de/~javahrd/>) an interactive Hertzsprung–Russell diagram as a Java applet
- BaSTI (<http://albione.oa-teramo.inaf.it/>) a Bag of Stellar Tracks and Isochrones, simulations with FRANEC code by Teramo Astronomical Observatory
- Leos Ondra: The first Hertzsprung-Russell diagram (<http://www.leosondra.cz/en/first-hr-diagram/>)



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