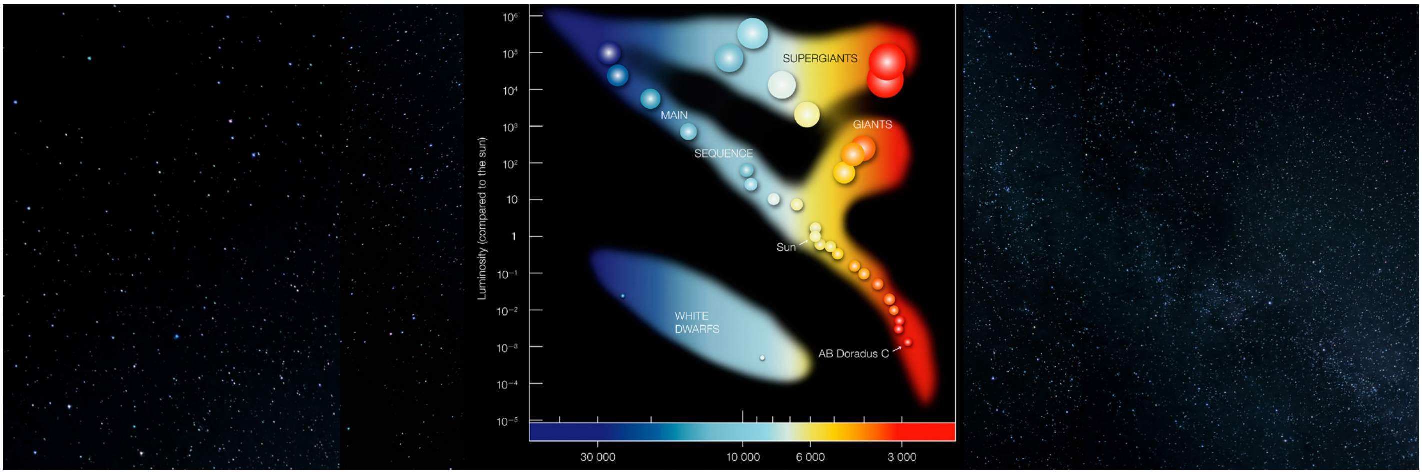
Science in School
The European journal for science teachers

ISSUE 76 – February 2026 **Topics** Astronomy/space



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A map of the stars

Umaimah Muffy

From notebook sketches to space-telescope data: explore how mapping starlight using the Herzsprung-Russell (H-R) diagram helps us trace the life stories of stars across the universe.

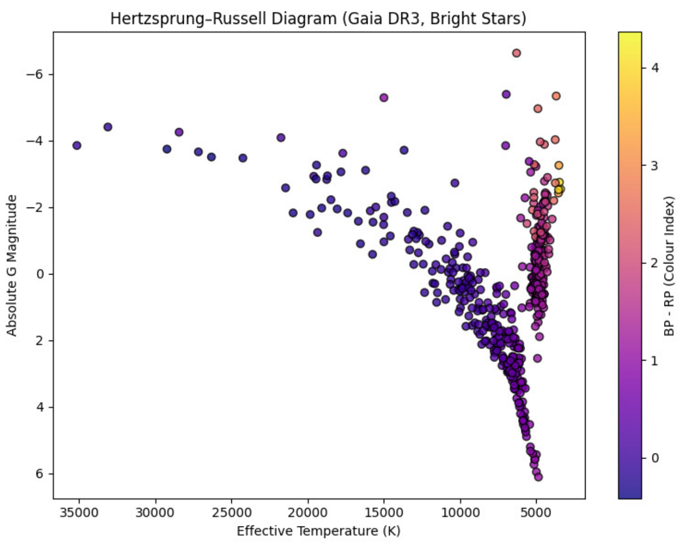
Reading the sky through data

Some stars blaze blue, others glow red. Some shine brilliantly, dominating the night sky, while others barely flicker. If you could draw the life story of every star in the universe, what would it look like?

Astronomers answer this question with a remarkable tool: the Hertzsprung-Russell (H-R) diagram, often described as "astronomy's map of the stars". Developed over a century ago by Ejnar Hertzsprung and Henry Norris Russell, this simple diagram shows the luminosity of a star against their surface temperature, revealing hidden patterns that explain how stars are born, evolve, and die.[1] Learn more about the historical background of the Hertzsprung-Russell diagram in [info sheet 1: historical roots].

Each point on the diagram represents a star at a particular stage in its life. As stars evolve, they move across the chart along different paths depending on their mass. For example, some stars move from the bright, hot regions of young blue stars towards cooler regions of the diagram, where they may evolve into red giants and eventually end their lives as white dwarfs.

In this activity, students will learn how to build their own H-R diagram using real stellar data – just like astronomers do. They will thereby discover how a single chart can unlock the grand story of our galaxy, from nearby stars to the discoveries made by the Gaia space mission, an ESA observatory mapping the Milky Way.[2]



H-R diagram generated in Python using Gaia Data Release 3 (DR3) dataset.

Image courtesy of the author

Activity 1: Plotting the Hertzsprung-Russell diagram

The estimated duration for this activity is 20–25 minutes.

In activity 1, students recreate their own H-R diagram using real data from 10–20 well-known stars, such as the Sun, Sirius, Vega, Betelgeuse, and Rigel.

The activity can be done in different ways:

- by hand on graph paper
- **OR** in Excel or Google sheets (using scatter plots)
- **OR** using Python (or Google Colab for a dynamic digital version)

Materials

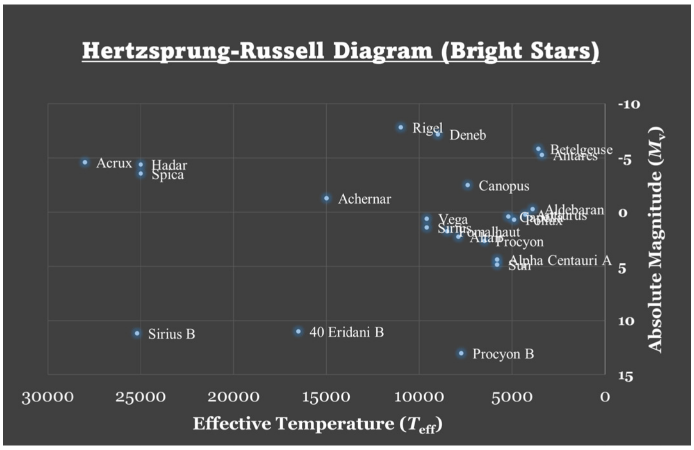
- Graph paper **OR** a computer with access to Excel/Google sheets **OR** Python Notebook (Google Colab)
- Depending on which method is used:
  - Excel plotting guide
  - Python plotting guide
- Infosheet: advanced concepts and data relationships
- Table 1: Sample data for plotting a classroom Hertzsprung-Russell diagram
- Activity 1 worksheet

Procedure

1. Use the following stellar data:
   a. Temperature (T or T_{eff}): The surface temperature of a star, which determines its colour. Blue stars are hotter, red stars are cooler (x-axis).
   b. Absolute magnitude (M_v): A star's brightness if it were placed at a standard distance of 10 parsecs from Earth (y-axis).
2. Plot each star as a point on the graph.
3. Optionally, colour-code points by spectral class to add visual contrast.
4. Observe the patterns that emerge: the main sequence, red giants, and white dwarfs.
5. Ask students to answer the questions below in the activity 1 worksheet. Possible answers to these questions are included in the activity 1 answer sheet.
   a) Why do most stars fall along a single curved band – the main sequence – instead of being scattered randomly?
   b) What might this suggest about how stars live and evolve?

Info box

- Temperatures are approximate and derived from standard spectral class-temperature mappings, suitable for classroom plotting.
- Absolute magnitudes are taken from established bright-star catalogues.
- These approximations are accurate enough to reproduce the characteristic shape of the real H-R diagram.



H-R diagram constructed in Excel using data from the brightest stars. The data is available here.

Image courtesy of the author

Activity 2: Evolutionary track of the Sun

In activity 2, students trace the evolutionary track of the Sun on the H–R diagram. The evolutionary track is the path a star follows on the H-R diagram as it ages and changes in temperature and brightness.

Estimated time: 20–25 min

Materials

- H-R diagram template (printed or digital from activity 1)
- "Evolution of the Sun" diagram or reference images (see below)
- Coloured pencils (if printed) or digital annotation tools
- Activity 2 worksheet

Procedure

1. While looking at the H-R diagram together, briefly recap with your students temperature, luminosity, and stellar classes.
2. Ask students to locate and label the Sun's position at key evolutionary stages on the H-R diagram, using the reference materials or guided hints.
   a. Protostar
   b. Zero-age main sequence
   c. Current main-sequence position
   d. Red giant phase
   e. Helium-burning/Horizontal branch (if included)
   f. White dwarf
3. Ask them to complete the table in the activity 2 worksheet, answering the following three questions for each of these stages (answers can be found in the activity 2 answers sheet):
   - How does the Sun's brightness change from one stage to the next?
   - How does its temperature change from one stage to the next?
   - What processes inside the Sun could explain these shifts?
4. Let students write a short summary on how a star's life stages determine its track on the H-R diagram.

Uncovering the life stories hidden in the stars

Now that the students have plotted the stars and observed the patterns, it's time to understand what the diagram reveals about the life of each star. The clusters and sequences that the students discovered are more than just points on a graph. They reveal fundamental properties of stars and how they evolve.

1. Understanding stellar properties

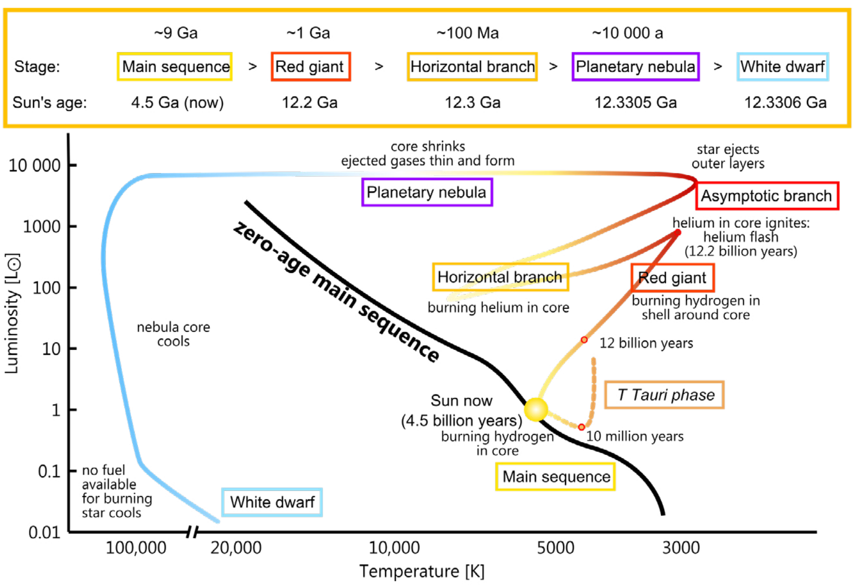
The H-R diagram plots stellar surface temperature against luminosity, which represents the total energy output of a star per unit time and reflects its intrinsic brightness. Temperature (or spectral type) is plotted on the x-axis and luminosity (or brightness compared to the Sun) is plotted on the y-axis. Despite only having these two quantities, every point on the diagram carries hidden information about the star's colour, size, and stage of life.

Good to know

Astronomers never measure a star's temperature directly. Instead, they analyse how much light the star emits in different colours, also known as its spectrum. From these colour patterns, they can infer the star's temperature, classify it, and place it on the H-R diagram.[3]

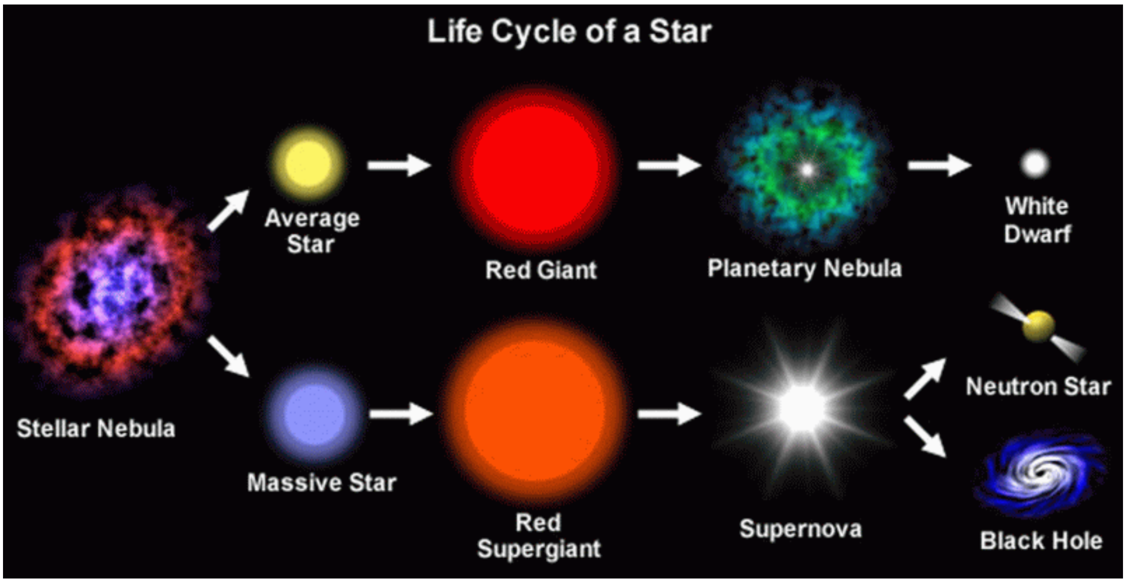
2. Mass and life stage

Each star's position on the H-R diagram is largely determined by its mass, which dictates how it lives and dies. More massive stars live fast and die young, while smaller stars like the



Evolution of the Sun from the main sequence to white dwarf.

Image: Szczureq/Wikimedia Commons, CC BY-SA 4.0



Evolution of a star along its lifetime depends on its initial mass.
Image courtesy of students.um.edu

Sun evolve slowly and end quietly. The main sequence on the H-R diagram is like a stellar highway, showing stars of different masses in the prime of their lives. The clusters of red giants and white dwarfs represent what happens when stars leave that highway.

3. Stellar evolution

By reading the H-R diagram, the life story of stars can be followed:

- **Main sequence**: the diagonal band on the H-R diagram where most stars (including the Sun) spend the majority of their lives fusing hydrogen in their cores
- **Red giants**: large, cool, and luminous stars in a late stage of evolution that have exhausted their core hydrogen and expanded
- **White dwarfs**: small, dense, faint stellar remnants; left after a star like the Sun has shed its outer layers

The plotted activity demonstrates these stages visually, showing how stars move across the diagram as they age.

Activity 3: Dive deep – mapping the galaxy with Gaia DR2

After plotting their own H-R diagrams, students have seen how patterns emerge in star brightness and colour. Now imagine doing this for over two billion stars! That's exactly what astronomers using ESA's Gaia mission have achieved.[2]

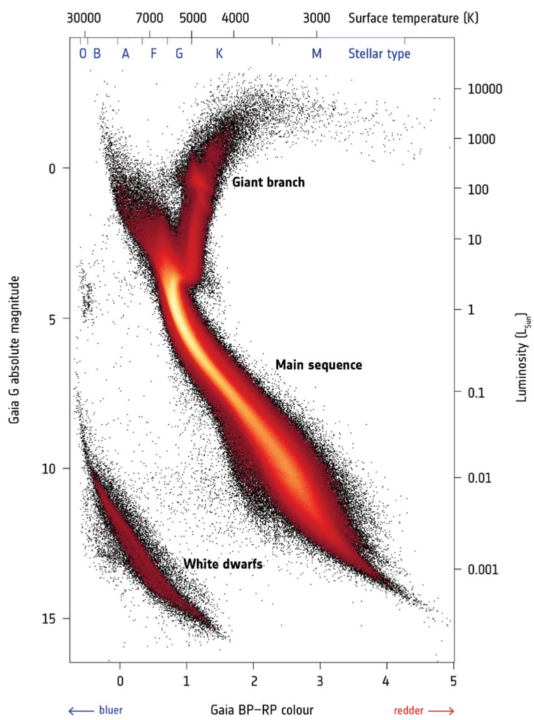
The Gaia mission, a European Space Agency project mapping the positions, distances, and motions of over two billion stars in the Milky Way, has produced the most detailed H-R diagram ever made. Using data from Gaia Data Release 2, astronomers plotted more than four million stars located within 5000 light-years of the Sun (Data Release 2).[4]

Compared with the earlier Hipparcos data, Gaia's diagram reveals remarkable new features: a thin main sequence, binary star tracks, red clumps of helium-burning stars, and even splits in white dwarf branches.[4,5]

By selecting stars based on their proper motion, astronomers can separate the galaxy's main populations:

- Thin disk: young, metal-rich stars
- Thick disk: older, metal-poor stars
- Halo: twin main sequences showing different chemical histories[6]

➔ GAIA'S HERTZSPRUNG-RUSSELL DIAGRAM



Hertzsprung-Russel diagram from the Gaia mission
Image taken from Ref. [5]

Gaia has even shown that our galaxy isn't static: it ripples and wobbles, like a giant wave spreading from its centre (like a pebble dropped in water). By comparing your small H-R diagram with Gaia's billion-star map, you can see how simple data visualization uncovers profound patterns and grows into cosmic discovery.[7] It shows how age, composition, and motion shape the Milky Way, and that stars are not randomly scattered but follow physical laws dictated by mass, energy, and time.

The following activity takes 15–20 min.

Materials

- Activity 3 worksheet

Procedure

Encourage students to think about the patterns they uncovered and what they reveal about the way science works. Possible answers to these questions are included in the activity 3 answers sheet.

1. What trends do you observe between temperature and luminosity on your diagram?
2. Which stars do not follow this trend, and what might their positions reveal about their stage of life?
3. How do your plotted results compare with Gaia's billion-star H-R diagram?
4. How could limited or uncertain data change the apparent shape of the H-R diagram and what biases might this introduce?
5. How does metallicity (element composition) influence star colour and brightness?
6. What surprised you most about your plotted data and why?
7. If you had to explain the H-R diagram to someone using only three sentences, what would you say? «

References

[1] Introduction to the H-R diagram: https://www.cosmos.esa.int/web/cesar/the-hertzsprung-russell-diagram

[2] The Gaia mission by the European Space Agency: https://www.esa.int/Science_Exploration/Space_Science/Gaia

[3] Video on how to construct H-R diagrams: https://science.nasa.gov/asset/hubble/constructing-the-hertzsprung-russell-diagram-for-globular-star-cluster/

[4] Brown AGA et al. (2018) Gaia Data Release 2: Summary of the contents and survey properties. *Astronomy & Astrophysics* **616**. doi: 10.1051/0004-6361/201833051

[5] A Gaia Hertzsprung-Russell diagram from 2018: https://www.esa.int/ESA_Multimedia/Images/2018/04/Gaia_s_Hertzsprung-Russell_diagram

[6] Hertzsprung-Russell diagrams from Gaia Data Release 2: https://www.cosmos.esa.int/web/gaia/gaiadr2_hrd

[7] The galaxy's great wave discovered by the Gaia mission: https://www.esa.int/Science_Exploration/Space_Science/Gaia/Gaia_discovers_our_galaxy_s_great_wave

Resources

- Discover the spectral types and temperatures of main sequence stars.
- Read about stellar classification.
- Learn about the different groups and stages seen in the Hertzsprung-Russell diagram.
- Check out this step-by-step guide on how to read an H-R diagram.
- Read about what the Gaia mission reveals about the colours of stars.
- Look at this student worksheet on H-R diagrams from the Nebraska Astronomy Applet Project.
- Explore an online lab exercise guide for students to learn about H-R diagrams.
- Find out what the stars are made of: Ribeiro CI, Ahlgren O (2016) What are stars made of? *Science in School* **37**: 34–39.
- Explore five inspiring STEM projects from ESA and the ESERO network: Cruz Niggebrugge C (2025) Back to School with space-related STEM projects from ESA and ESERO 2025-2026. *Science in School* **74**.
- Discover how astronomers study the past of the Milky Way and peer into its future: Forsberg R (2023) Galactic Archaeology: how we study our home galaxy. *Science in School* **64**.
- Learn more about the Sun and its source of power: Westra MT (2006) Fusion in the Universe: the power of the Sun. *Science in School* **3**: 60–62.
- Read an article on fusion reaction in the Universe and where we come from: Boffin H, Pierce-Price D (2007) Fusion in the Universe: we are all stardust. *Science in School* **4**: 61–63.
- Learn to model stellar life cycles and explore stellar evolution: Marshall J (2025) Wall of stars: illuminate stellar life cycles with physics and coding. *Science in School* 74.
- Discover the questionable behaviour of white dwarfs: Maxwell T (2025) Celestial cannibalism: investigating cataclysmic variable stars. *Science in School* **75**.
- Find out how stars die: Székely P, Benedekfi Ö (2007) Fusion in the Universe: when a star dies…*Science in School* **6**: 64–68.

- Measure distances to the stars like real astronomers with this classroom activity: Pössel M (2017) Finding the scale of space. *Science in School* **40**: 13–18.
- Be amazed at how easy it is to estimate the Sun's temperature by using just some water, sunlight and simple equipment: Kardaras I (2025) Estimation of the Sun's temperature without leaving the school. *Science in School* **72**.

AUTHOR BIOGRAPHY

Umaimah Muffy, a space sciences graduate, is an aspiring writer and science communicator. She blends her love for astronomy, art, and storytelling to craft engaging science narratives that explore how art can deepen scientific understanding. She works in marketing and engagement at the Pakistan Maritime Museum, where she organises educational events to inspire curiosity and learning. She lives with two curious cats who are her devoted muses and critics.