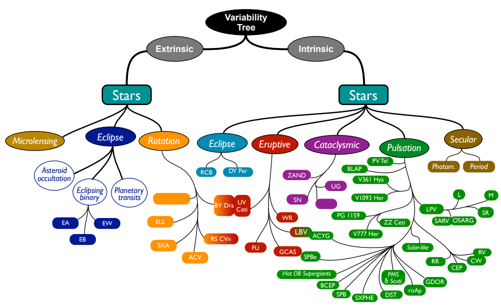
62. Variability across the HR Diagram

In my previous essay, #61, I looked at the principles and methods from which huge numbers of variable stars are being discovered and classified as part of Gaia's astrometric and photometric survey of our Galaxy.

These include both 'intrinsic variables', in which the luminosity of the star itself changes with time, as well as 'extrinsic variables', in which apparent variability occurs because something affects the stellar light on the way from the star itself to us on Earth.

Of more than two billion stars being surveyed, Data Release 2 (from just the first two years of the mission, between July 2014 and May 2016, and made public in April 2018), contains 550 737 variable sources classified by the project, comprising 228 904 RR Lyrae stars and 11 438 Cepheids; 151 761 long-period variables; 147 535 stars showing rotation modulation; 8882 Delta Scuti and SX Phoenicis stars; and 3018 short-timescale variables.



Courtesy: Laurent Eyer

A classification tree of variable stars

Most importantly, and in contrast with all other surveys, *every star* will have a measured distance, space motion, and other supplementary data, providing the information required for interpreting variability as a function of stellar luminosity, Galactic population, Galactic location, as well as age and metallicity.

Extrapolating to a possible 10-year mission, the number and variety of variable stars will provide a data set likely to occupy both observers and theoreticians with material for studies of variability, at both an individual and statistical level, for a very long time.

As just one example of why variability results from Gaia are expected to be so far-reaching are the important class of Cepheid variables, more than 11 000 of which have been characterised in Gaia DR2. The physics underlying their regular variability, the κ-mechanism, is reasonably well understood, and it depends on the changing opacity of helium in the outer layers of the star according to its ionisation state.

The strong relationship between their luminosity and pulsation period, discovered by Henrietta Swan Leavitt in 1908, established Cepheids as important indicators of Galactic and extragalactic distances, and remains central in discussions of the Hubble constant today. While uncertainties remain due to the effects of metallicity and interstellar extinction, these and others are expected to be clarified enormously by Gaia.

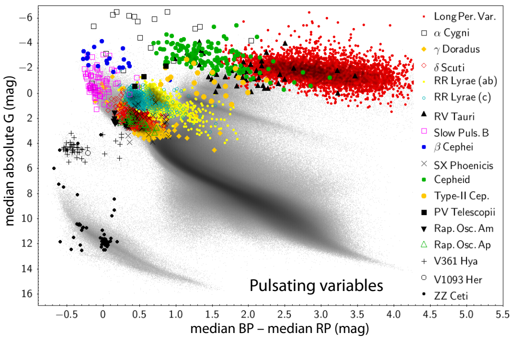
The older, and more common, RR Lyrae variables similarly result from the κ-mechanism, but their period–luminosity relation has a stronger dependence on metallicity. The Gaia distances will allow the more than 220 000 RR Lyrae variables known so far to map out the effects of metallicity throughout our Galaxy.

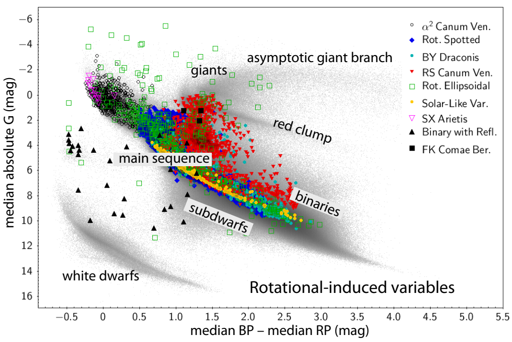
Variable stars have long been recognised as offering deep insights into stellar structure and evolution. Similarly, the Hertzsprung–Russell diagram provides a quantitative visualisation of all stages of stellar evolution. Together with its empirical analogue, the colour–magnitude diagram, it has enabled many advances in stellar astrophysics.

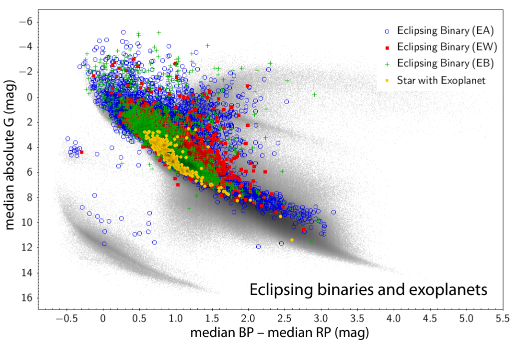
By combining the different types of variability data with the Gaia distances, the colour versus absolute magnitude for variable stars can now be reconstructed in any direction in the Milky Way, and for different populations. This builds on previous work based on the Hipparcos results (Eyer et al. 1997), but on a much vaster scale.

A first investigation has been carried out by Eyer et al. (2019), who placed these half a million variable stars in a Galactic diagram of colour versus absolute magnitude, focusing on pulsating, eruptive, and cataclysmic variables, as well as on stars that show apparent variability due to stellar rotation and binary eclipses.

In these three figures from their work, the grey background delineates key stellar populations: the main sequence (broadened due to close binary systems), the red clump (and its long tail due to interstellar extinction), the horizontal branch, the red giant and asymptotic giant branches, along with the white dwarfs, the subdwarfs, and the supergiants.



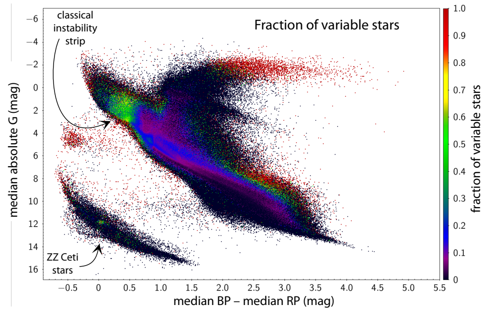




The diagrams are presently uncorrected for interstellar extinction, which blurs the boundaries (and restricts theoretical inferences) between variability classes.

Amongst Gaia objects showing rotational-induced variation are three primary categories: spotted stars, stars deformed by tidal interactions, and objects whose variability is due to light reflected by a companion, viz. binary systems with a strong reflection component in the light curve, in which the hotter component's stellar light is re-radiated from the cooler companion's surface.

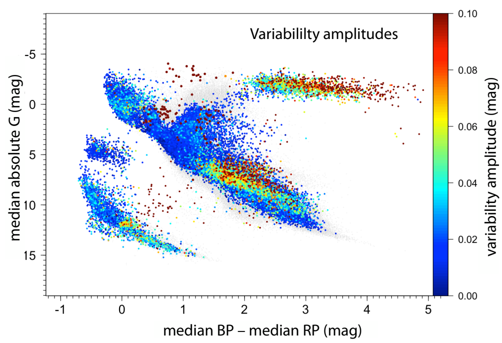
From these data, variable object fractions and typical variability amplitudes can be rigorously estimated throughout the diagram. Thus Eyer et al. used a sample of 13 million stars with heliocentric distances out to 1 kpc, satisfying specific astrometric and photometric criteria, and at a precision of about 5–10 mmag.



They identified variability in 9% of stars, with 50–60% in the classical instability strip being variable. For evolved stars and red giants, higher luminosity and redder colour both imply a higher probability of variability, while the red clump shows a very small fraction of variables.

The classical ZZ Ceti stars (white dwarfs featuring fast non-radial gravity-mode pulsations) are particularly concentrated in magnitude and colour, with variability in about half of the stars. This concentration is attributed to the partial ionisation of hydrogen in the outer envelopes of white dwarfs, which is only developed over a narrow range of temperature (and therefore colour).

The diagram of variability amplitudes shows a number of distinct clumps and instability regions, directly related to the various variability classes.



Finally, individual variable stars show both a changing absolute magnitude and a changing colour index throughout their periodic cycle. For example, pulsating stars (including long-period variables, Cepheids and RR Lyrae stars), are all bluer when brighter, showing that their brightness variations are dominated by a change in temperature, rather than in radius.

A movie of the changing loci of representative variable stars across the colour–magnitude diagram can be found at `cosmos.esa.int/web/gaia/gaiadr2_cu7`.