Stars that actually twinkle

and some that go BOOM!

Measuring brightness: a primer

- We see light coming from stars. ☒
- We see light originating from stars, which has travelled through space, a lot of interstellar dust, gas and finally the atmosphere. ☑
- We will conveniently ignore all of this.
- So we have light coming from a star.
  - What do we measure?
  - Whatever we do measure, is it the same regardless of distance of the star, or in other words,
  - How do we relate the intrinsic brightness of a star with the brightness we see from Earth.

Magnitudes

$$m_1 - m_2 = -2.5\log_{10}\left(\frac{F_1}{F_2}\right)$$

m = apparent magnitude (what we see)

F = Flux from the star. Measured in W m^{-2}

This logarithmic rescaling is a relic of old conventions, but is convenient.

Magnitudes (there are more)

$$M = m - 5\log_{10} d_{pc} + 5$$

M = absolute magnitude, if the star were 10 pc away from us.

d_{pc} = distance in parsec

Filters (yay, more magnitudes)

- Looking at light in bands of wavelengths, accomplished by using filters.
- Common filters : UBV(RI)†, grizy‡, HJK*. Each mission has their own version, based on the kind of astronomy they want to do.
- Multi-wavelength studies give colour

†Johnson-Cousins Photometric System, ‡PanSTARRS, *2MASS

Colour index : difference between magnitudes in two filters

Colour index: a proxy for temperature.

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See also:
https://en.wikipedia.org/wiki/Photometric_system#Filters_used
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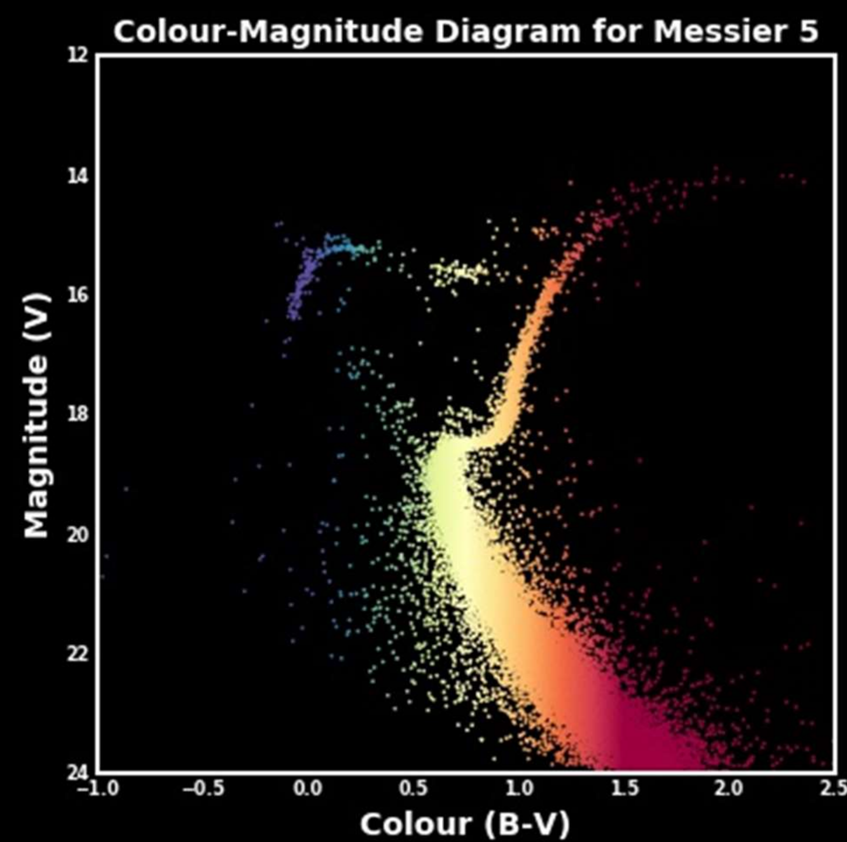
Well, what if we combine them?

- Hertzsprung-Russell diagrams (took me three tries to get the spelling right) or HR diagrams plot Luminosity vs Temperature of the star.
- We know now that Luminosity ~ Magnitude and Temperature ~ Colour, so if we plot those, we get a Colour Magnitude Diagram
- If we plot an HR diagram of a lot of stars, we are going to see something extraordinary.

This has been plotted using Hubble data for a globular cluster.

We see the main sequence, a turn off point, and then the so called Red Giant/Supergiant stage, and other stages in the life cycle of a star



Data taken from HST (MAST):
https://archive.stsci.edu/prepds/hugs/

Henrietta Leavitt,
the mother of modern transient astronomy

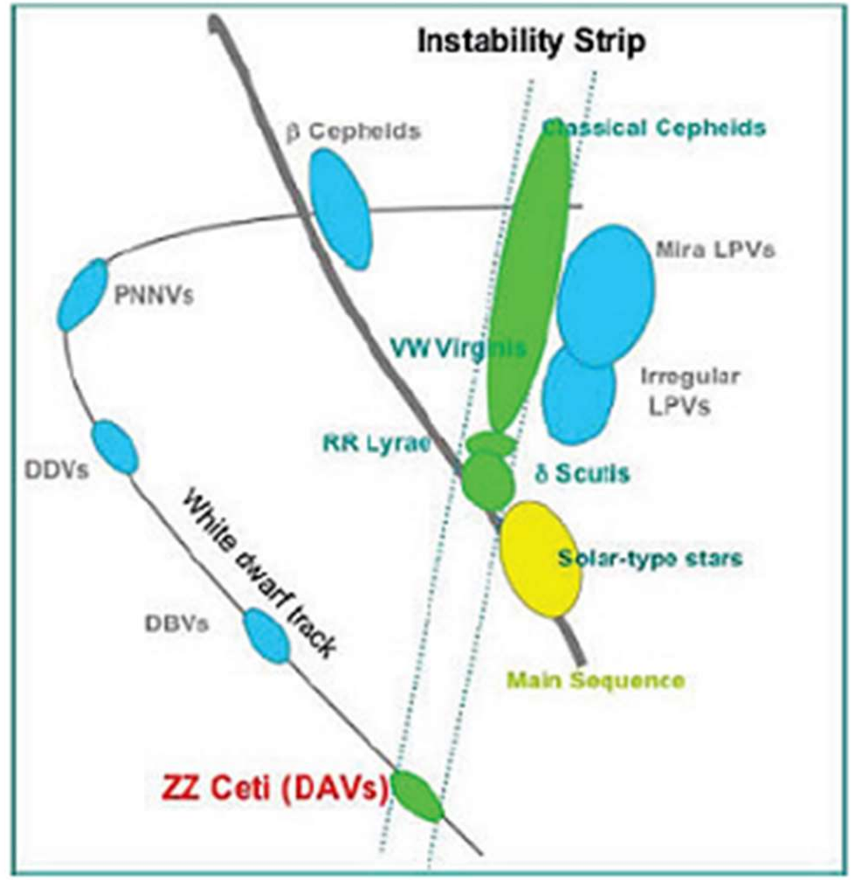
(I called her that)

- Discovered a bunch of variables in the Large Magellanic Cloud, and discovered a correlation between the Period of variability and their relative magnitude (which corresponds roughly to Absolute magnitude because they are approximately at the same distance)
- Several years later, we still use Cepheids, although we now have different categories, as well as other types of variables to determine distances

Where are these Cepheids?

Variable stars fall on the instability strip.

Note that the Classical Cepheids lie in an almost vertical region, i.e. almost the same temperature.



The Instability strip in relation to various types of stars. Cepheids, RR Lyrae, W Virginis, and ZZ Ceti stars can all be found in this region, as well as other, less common variable stars. Image is used for education purpose only. Credit: http://astronomy.swin.edu.au (Swinburne University of Technology)

But why? A theoretical ‘justification’

\begin{equations}

A star is essentially a ball of gas particles. So we can use the gravitational virial theorem to say:

$$\frac{GM^2}{R} = 2N\frac{3}{2}kT$$

We also know that the luminosity of a star can be approximated by Stefan’s Law:

$$L = \sigma A T^4$$

For a more detailed analysis, see: https://www.astro.princeton.edu/~gk/A403/pulse.pdf

The fundamental mode of oscillations would correspond to a period of :

$$\Pi = \frac{4R}{v_s}$$

Velocity of sound in a medium:

$$v_s = \frac{\text{(Bulk Modulus)}}{\text{(Density)}}$$

And assuming adiabatic expansion/contraction

$$v_s = \frac{\gamma P}{\rho}$$

If anyone is still awake,

A controversial move $$PV = NkT$$

Results in a very satisfying looking answer:

$$\Pi = (\text{constant}) * L^{3/4} T^{-3} M^{-1/2}$$

Making this a bit more Astronomy-y

$$\log_{10} \Pi = -0.3M + (\text{constant})$$

royally ignoring the terms for Mass and Temperature.

Why is this useful?

We can find M!

We can also measure m

So we can find distance to the star.

We can also use this to calibrate the Cosmic Distance Ladder.
(sounds awesome. Is awesome!)

How do we calibrate?

Find the distance to a number of Cepheids, so that we know the absolute magnitude. Find the coefficients in the PLR. Use as required.

Wait...something's missing: Systematic Errors

Go back into the calculation, and carefully look at all the things we did. Where can systematic errors creep in?

Wait...something’s missing: Systematic Errors

- Non-black body radiation
- Vibrations in overtones
- Effect of temperature, i.e. Colour
- Mass
- Metallicity

Finding Periods

Given a time series, how do you find periodicity?

Fourier transforms?

Fourier Power Spectrums?

Periodograms?

Least-Squares fit?

Lomb-Scargle Periodogram

For a very thorough and accessible review, see:
https://arxiv.org/abs/1703.09824